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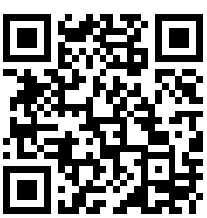

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# TERRESTRIAL MAGNETISM
## AND
# ATMOSPHERIC ELECTRICITY

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# TERRESTRIAL MAGNETISM
AND
# ATMOSPHERIC ELECTRICITY
## AN INTERNATIONAL QUARTERLY JOURNAL

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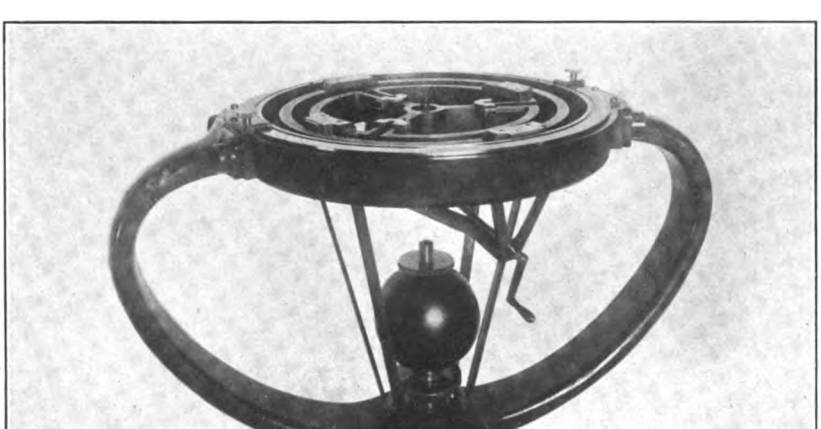

FIG. 1.

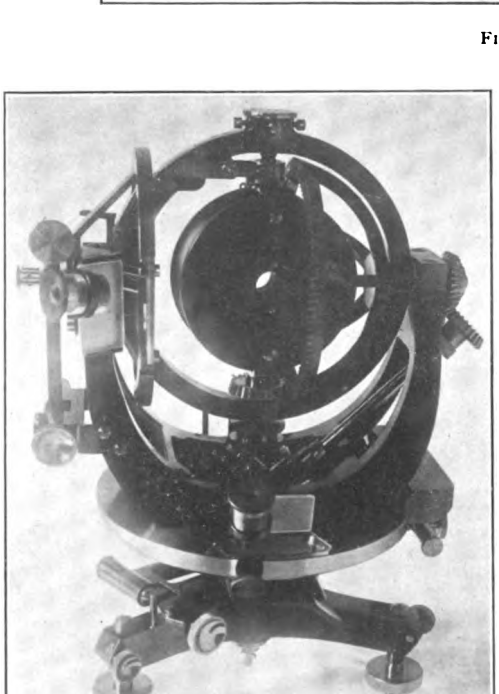

FIG. 2.

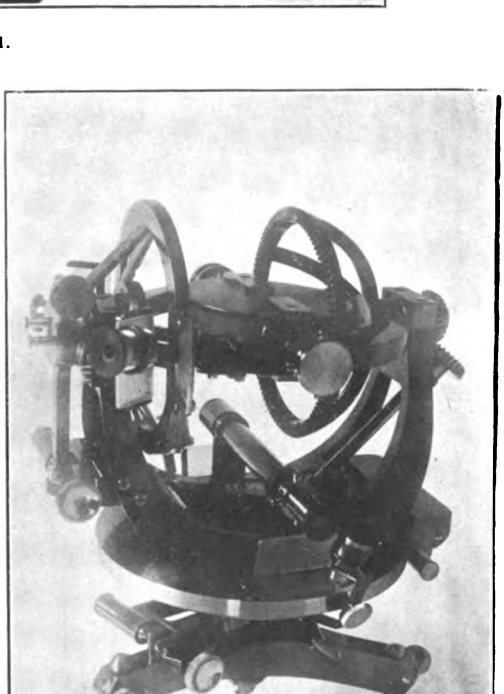

FIG. 3.

REVERSIBLE GIMBAL STAND AND MARINE EARTH INDUCTOR IN USE ON THE "CARNEGIE."

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# *Terrestrial Magnetism*

*and*

# *Atmospheric Electricity*

VOLUME XVIII MARCH, 1913 NUMBER 1


## THE THEORY OF THE EARTH INDUCTOR AS AN INCLINOMETER.


BY N. E. DORSEY.


The earth inductor, in its most complete form, as used for the measurement of the magnetic inclination, consists essentially of a coil ($C$) of insulated wire which can be rapidly and continuously rotated about an axis ($AB$), Fig. 1, which coincides with a diameter of the coil. The axis $AB$ is capable of measured rotation about the two mutually perpendicular axes, one horizontal, $DE$, and the other vertical, $V$; by construction $AB$ is perpendicular to $DE$. Thus the direction of $AB$ can be made to coincide with that of any radius of a sphere having its center at the intersection of the three axes. In the future we shall speak of $AB$ as the axis of rotation, of $DE$ as the inclination axis, and of $V$ as the azimuth axis, and shall call the plane which includes both $AB$ and $DE$ the "inclined plane" of the instrument. The windings of $C$ are connected by means of slip rings, or a commutator, with a galvanometer or other instrument by means of which the current induced in the coil by the Earth's field can be detected or measured, depending upon the manner in which the instrument is used.

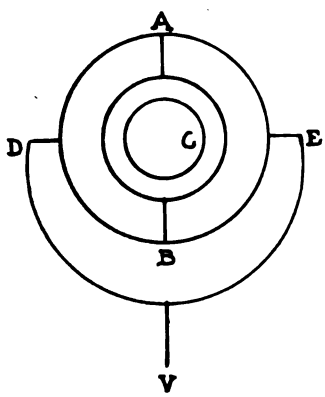


FIG. 1.

It is our object to consider in some detail: (1) the various conditions under which such an instrument can be used for the determination of the inclination; (2) the procedure that must be




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adopted in order to obtain the most reliable results; (3) the effects of various maladjustments; and (4) the applicability of the instrument to marine work.[1]

## Physical Considerations.

It is at once evident that when the coil is rotating about $AB$ there will always be an alternating electromotive force generated in it, excepting in the single case in which $AB$ coincides exactly with the direction of the resultant magnetic field. Hence, if the coil is provided with slip rings, and an alternating current detector, such as a telephone receiver, is used, there will always, with the single exception noted, be an alternating current in the detector. Since it is practically necessary that such detectors be used as null instruments, it is evident that they can be employed only under those conditions in which the instrument can be firmly mounted and the axis of rotation can be placed strictly in the direction of the resultant magnetic field.

If the coil is provided with a commutator that instantaneously reverses its connection with the external circuit when the plane of the coil is parallel to the inclination axis, and if a continuous current galvanometer is used as the detecting instrument, then, in general, there will be a current through the galvanometer. The sole exception, as in the former case, is when the axis of rotation is parallel to the resultant field. However, when the coil is rotated rapidly as compared with the period of the galvanometer, the latter will indicate the mean current flowing through it. Hence, if we adjust the direction of the axis of rotation—by rotation about the other two axes of the instrument—so that the commutations occur exactly at the crests and at the troughs of the alternating current, then during each half revolution of the coil exactly as much electricity will have flowed through the galvanometer in the negative direction as in the positive, so that the mean current will be zero and the galvanometer will remain undeflected.

Hence, the use of a commutator and a galvanometer increases the flexibility of the instrument, in that it allows observations to be taken when the inclination axis, $DE$, does not lie in the magnetic prime vertical, and thus makes possible exmeridian observations.

It is evident that the maximum electromotive force induced in the coil during its revolution will be proportional to the component

[1] Although certain conclusions stated in the latter portion of this paper are well known in connection with dip-needle work, it seemed desirable to repeat them in this connection.

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of the magnetic intensity which is perpendicular to the axis of rotation, and will occur when the plane of the coil[2] includes the direction of the magnetic field; the total induction through the coil is then increasing at its greatest rate. For a given azimuth of the inclination axis, the position of the coil when this occurs will vary as the inclination of the rotation axis is changed, and, for a certain angle, will coincide with the inclined plane of the instrument. Then the commutation will occur at the crests and the troughs of the induced electromotive force; did the current not lag behind the electromotive force, this setting would be the one that would correspond to a zero deflection of the galvanometer.

But owing to the inductance of the circuit, the current lags behind the electromotive force by an angle depending upon the electrical constants of the circuit and upon the speed of rotation of the coil. The curves *a* in Fig. 2 represent the relation between

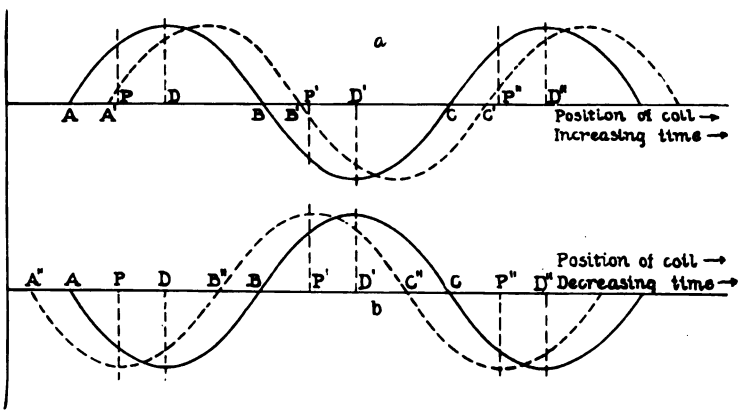


FIG. 2. *The continuous curves represent the electromotive force, and the dotted curves the current in the coil.*

the values of the electromotive force and of the current and the position of the coil. The electromotive force, represented by the continuous line, attains a certain value, say zero, when the coil is in the position $B$, but the coil must turn beyond this point by an angle of $BB'$ before the current, represented by the dotted line, attains its corresponding value. $BB'$ is the angular lag of the current behind the electromotive force. Hence, in exmeridian observations the setting for zero deflection is affected by the speed

[2] By the "plane of the coil" is meant the component of its plane parallel to the axis of rotation; the component perpendicular to this axis is ineffective.

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of rotation of the coil, and it becomes necessary to work at a definite speed.

If for a certain speed of rotation, and a certain setting of the inclined plane, commutation occurs at $P$ and $P'$ (Fig. 2) and the lag is $BB'$, then the quantity of electricity that passes through the galvanometer will be represented by the area of the current curve included between $P$ and $P'$, the portion $PB'$ being positive and $B'P'$ being negative. If now we reverse the direction of rotation, the condition of affairs is as shown in the curves $b$ of Fig. 2; then the coil will be in the position $B''$ when the current has the value which corresponds to that of the electromotive force at $B'$, the lag $BB''=BB'$, if the speed is the same as before. It is evident that the area of the current curve between $P$ and $P'$ can be the same for both directions of rotation only in the special case when $P$ and $P'$ lie exactly at the crest and at the trough of the electromotive force wave; that is, at $D$ and $D'$.

Hence, if we adjust the position of the axis of rotation until the deflection observed when the coil is spun in the positive direction is exactly equal to that observed when the coil is spun at the same speed in the negative direction, then the setting is exactly that which would have given a zero deflection had there been no lag. We shall call this position the *position of balance.* For this setting the inclined plane is parallel to the direction of the Earth's field.

Owing to the friction at the brush contacts, thermal currents will be produced which will have the effect of causing the effective zero of the galvanometer—that from which we should measure the deflections—to differ from that observed when the coil is at rest. This difference will, in general, depend upon the speed of rotation of the coil; hence, to eliminate it, the speed must be kept constant. If these thermocurrents are independent of the direction of rotation of the coil, then, so far as these currents are concerned, a true balance has been obtained when the deflection for a positive spin of the coil is equal to that for a negative spin at the same speed. Hence, when the above assumption is correct, the effects both of lag and of thermocurrents are eliminated by working at a constant, fixed speed and setting the axis of the coil so that the deflection for a positive spin is the same in magnitude and in direction as for a negative spin.

We have so far assumed that instantaneous commutation occurs when the coil lies in the inclined plane of the instrument. If this

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is the case, then, when the inclination axis lies in the magnetic prime vertical, the commutation occurs when the absolute value of the induced electromotive force is zero and the sensibility with which we can detect slight departures of the axis of rotation from the direction of the field is a maximum; however, small displacements of the brushes from this position decrease the sensibility but very slightly. For exmeridian observations we have seen that the balance depends upon the commutation taking place at definite positions with reference to the crests and to the troughs of the electromotive force, hence for such observations the observed setting will depend upon the position of the plane of commutation and so the positions of the brushes become of importance. By the plane of commutation is meant that plane in which the coil lies at the instant of commutation. The exact effect that is produced by a small angle between the inclined plane and the plane of commutation will be considered later. Here it will suffice to call attention to the fact that if the inclined plane be placed in the magnetic meridian and it be found that the deflection observed for a positive spin is exactly equal to that observed for a negative spin, then, by what has gone before, it is evident that the plane of commutation is parallel to the inclined plane. If the two deflections are not equal, rotate the instrument about its azimuth axis, keeping the inclined plane vertical, until they are equal. Then the angle through which the inclined plane has been turned from the magnetic meridian is equal to the angle between it and the plane of commutation.

In general commutation is not instantaneous, but at each commutation there is a certain angular interval during which there is no current through the galvanometer. This may result either from the circuit being broken during this interval or from the coil being short-circuited by the brushes, one or both making contact with both segments of the commutator at the same time. We shall call these intervals the commutation breaks, and we shall regard the phenomena occurring during one rotation of the coil as made up of two phases, each measured from the middle of the preceding to the middle of the following commutation break. Thus, the angular duration of the two phases will be exactly 360°, and, if one is less than 180°, by an angle $2\xi$; the other will exceed 180° by the same amount. Whenever $\xi$ is not zero, and the two breaks are of equal duration, it is easily seen that the mean plane of commutation (*i. e.*, the plane which bisects the acute angle

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between the two positions of the plane of the coil which correspond to the two commutation breaks) must replace what heretofore we have called the plane of commutation. One phase begins at an angle $\xi$ before the plane of the coil coincides with this plane, and ends at an angle $\xi$ after it has passed this plane; the other phase completes the revolution. It is evident from Fig. 3, that if the

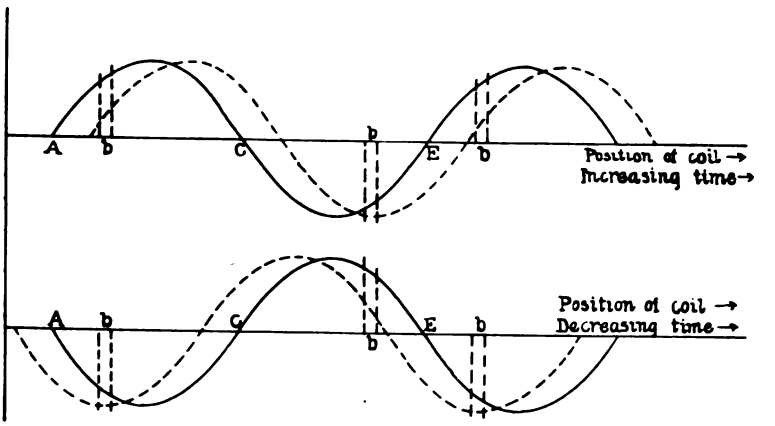


FIG. 3. *The continuous curves represent the electromotive force, and the dotted curves the current in the coil.*

breaks occur at the points $b$ so situated that successive breaks are symmetrically placed with reference to the points $A$, $C$, $E$, and if the breaks are of equal angular length, then the effect of the lag of the current will be the same for a positive spin as for a negative one, and consequently the criterion already established for the elimination of the effect of the lag, *viz.*, that the galvanometer deflection for a positive spin shall be exactly the same as for a negative one, determines the condition that the breaks shall be so placed. But when the breaks are thus symmetrically placed, the angle between the position of the coil at the first break and its position at the following crest of the electromotive force wave equals the angle between its position at the trough and its position at the following break; hence the mean plane of commutation coincides with the positions of the coil at these crests and troughs. Accordingly, for this adjustment, the mean plane of commutation includes the direction of the magnetic field of the Earth. If the breaks are not of equal lengths, and $\xi$ is not zero, the adjustment is slightly different from that just given, and this

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difference will be shown to depend upon the difference in the angular lengths of the commutation breaks. In practice $\xi$ is small, and the breaks are so nearly equal that this difference is negligible.

There is one further effect of the inductance of the circuit to be considered, *viz.*, the fact that the current can not establish itself instantaneously, neither can it be broken instantaneously. If the ratio of the inductance of the circuit to its resistance is sufficiently small, as will usually be the case, the practical result of this effect can be represented by a slightly decreased value of the current during a very short interval in the first part of each phase. When the adjustment is such that otherwise the deflection is the same for spins in opposite directions, this effect will merely reduce each deflection by the same amount and hence will leave them equal.

Accordingly we may conclude that, in all conditions when the deflection for a positive spin is equal to that for a negative spin at the same speed, the plane of commutation includes the direction of the Earth's field, unless the commutation breaks are sufficiently unequal, are separated by an angle sufficiently different from $\pi$, and the lag is sufficiently great to make the effect of the delay in the starting of the current appreciable. These effects should be negligible in a well constructed instrument, and it will be shown that, for a given speed of rotation, they can be made zero by adjusting the brushes until the deflection for this speed of rotation, when the inclined plane of the instrument is exactly in the magnetic meridian, is independent of the direction of spin. Excepting in the complete mathematical treatment immediately following, it will be assumed that this adjustment has been made. In the future the condition under which the deflection of the galvanometer is independent of the direction of spin will be referred to as the *condition of balance.*

Since it has been seen that when the brushes are adjusted as just specified a balance can occur only when the inclined plane includes the direction of the Earth's field, and as it is evident that, when this is the case, the angle between the axis of rotation and the direction of the Earth's field is a minimum for that particular azimuth, the above conclusions may be summed up thus: For any particular setting in azimuth, *a balance occurs when the angle between the axis of rotation and the direction of the Earth's field is a minimum;* i. e., *a balance occurs when the axis of rotation exactly coincides with the position that would be taken by a perfect dip needle when adjusted in the same manner.*

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As it is frequently desirable to know the magnitudes of the various effects considered, a mathematical discussion of the subject seems desirable.

## Mathematical Relations.

Since all angular measurements are made upon circles attached to the earth inductor, all quantities will be referred to polar coordinates fixed in the inductor. Regard the azimuth axis, positive downwards, as the polar axis, and the plane through the azimuth

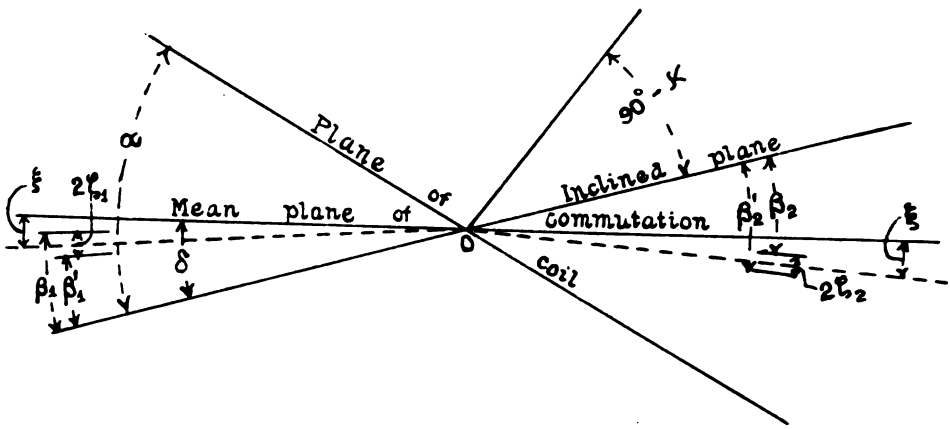


Fig. 4. *The plane of the figure is perpendicular to the axis of rotation of the coil. The latter intersects the plane at O. The unmarked solid line is the intersection of the plane containing both the axis of rotation and the direction of the Earth's magnetic field.*

axis and perpendicular to the plane containing both the azimuth and the inclination axis as the meridional plane. The positive half of this plane will be regarded as fixed by certain marks on the instrument and positive azimuth shall be measured from the positive half of this plane in the clockwise direction when observed in the positive direction of the polar axis. In a perfect instrument the inclination axis will be perpendicular to the azimuth axis. The instrument will be considered normally adjusted when the azimuth, or polar, axis is vertical, and the meridional plane coincides with the magnetic meridional plane and has its positive half towards the north. The positive end of the axis of rotation of the coil is that end which lies in the positive half of the meridional plane of the instrument. A direction of rotation about any radius vector will be considered positive when it is right handed,

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*i. e.*, appears clockwise when viewed from the origin in the positive direction of the radius vector. A certain face of the coil, arbitrarily marked, will be called the positive face; magnetic induction through the coil from its negative face to its positive face will be regarded as a positive induction; and the angular position of the coil will be measured from its position when parallel to the inclined plane of the instrument and with the normal drawn from its positive face lying in the positive half of the instrumental meridional plane. It will be assumed that the coil is wound upon a non-conducting form, and that the effect of the currents induced in the stationary portions of the instrument is negligible. The presence of a conducting form not only increases the complexity of the mathematical considerations without altering the nature of the conclusions, but also decreases the sensibility of the instrument. Other quantities needed, and their symbols, are as follows:

$F$ = total magnetic intensity of the Earth's field in magnitude and direction,

$I$ = magnetic inclination,

$I_1$ = complement of the polar angle, as measured by the inclination circle, of the north end of the axis of rotation of the coil,

$\theta''$, $\phi''$ = polar angle and azimuth, respectively, of $F$,

$\theta'_1$, $\phi_1'$ = polar angle and azimuth, respectively, of the north end of the axis of rotation of the coil,

$\theta$, $\phi$ = polar angle and azimuth, respectively, of any other point,

$\gamma$ = angle between $F$ and the axis of rotation,

$\delta$ = angle around the axis of rotation from the inclined plane of the instrument to the mean plane of commutation,

$\kappa$ = complement of the angle between the plane containing $F$ and the axis of rotation, and the inclined plane of the instrument; it is measured right-handedly about the axis of rotation, see Fig. 4,

$2\zeta_1$, $2\zeta_2$ = angular duration of the commutation breaks, $\zeta_1$ being the one that occurs the nearest to the zero position of the coil,

$2\xi$ = angular duration by which each phase differs from $\pi$, one phase exceeding and the other falling short of $\pi$ by this amount,

$\alpha$ = angle by which the coil has been turned from its zero position,



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$\omega$ = angular velocity of the coil,
$t$ = time counted from $\alpha = 0$,
$A$ = effective area of the coil,
$B$ = total magnetic induction through the coil in the positive direction,
$E$ = electromotive force produced by the change in $B$,
$i$ = current at the time $t$,
$L$ = self-inductance of the entire circuit,
$R$ = resistance of the entire circuit,
$\lambda$ = angular lag of the current $= \tan^{-1} \omega L/R$,
$q_1$, $q_2$ = quantities of electricity that pass through the galvanometer in the positive direction during each of the two phases into which each revolution of the coil has been divided,
$Q_r$, $Q_l$ = total quantities of electricity that pass through the galvanometer per turn of the coil for right-handed and left-handed spins, respectively,
$e_r$, $e_l$ = thermal electromotive forces for right-handed and left-handed spins of the coil, respectively,
$\epsilon$ = small error in the adjustment or construction of the instrument, and
$\eta$ = small error which the error $\epsilon$ produces in the computed value of $I$.

For a right-handed rotation of the coil

$$B = AF \sin\gamma \cos(\alpha - \kappa)$$

$$E = -\frac{dB}{dt} = AF \sin\gamma \sin(\alpha - \kappa)\frac{d\alpha}{dt}$$

$$= AF\omega \sin\gamma \sin(\alpha - \kappa)$$

It is known that the current, $i$, must satisfy the equation

$$L\frac{di}{dt} + Ri = e_r + E$$

or, since $\alpha = \omega t$,

$$\omega L\frac{di}{dt} + Ri = e_r + AF\omega \sin\gamma \sin(\alpha - \kappa)$$

The general solution of this equation is

$$i_r = \frac{e_r}{R} + k e^{-\alpha R/\omega L} + \frac{AF\omega}{(R^2+\omega^2L^2)^{\frac{1}{2}}} \sin\gamma \sin(\alpha - \kappa - \lambda)$$

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which is mathematically equivalent to

$$i_r = \frac{e_r}{R} + k e^{-\alpha \cot \lambda} + \frac{AF\omega}{R} \cos \lambda \sin \gamma \sin (\alpha - \kappa - \gamma) \qquad (1)$$

where $k$ is a constant of integration and $e$ is the base of the natural system of logarithms.

During the first phase, the circuit is closed only while $\alpha$ varies from $\beta_1$ to $\pi + \beta_2$ where $\beta_1 = \delta - \xi + \zeta_1$ and $\beta_2 = \delta + \xi - \zeta_2$; and $i_r = 0$ when $\alpha = \beta_1$. Introducing the latter condition into equation (1) we find

$$i_r = \frac{e_r}{R} \left\{ 1 - e^{(\beta_1 - \alpha) \cot \lambda} \right\}$$
$$+ \frac{AF\omega}{R} \cos \lambda \sin \gamma \left\{ \sin (\alpha - \kappa - \lambda) - e^{(\beta_1 - \alpha) \cot \lambda} \sin (\beta_1 - \kappa - \lambda) \right\}$$

Hence

$$q_1 = \int i_r \, dt = \frac{1}{\omega} \int_{\beta_1}^{\pi + \beta_2} i_r \, d\alpha$$
$$= \frac{e_r}{R\omega} \left\{ \pi + \beta_2 - \beta_1 + (e^{(\beta_1 - \beta_2 - \pi) \cot \lambda} - 1) \tan \lambda \right\}$$
$$+ \frac{AF}{R} \cos \lambda \sin \gamma \left\{ \cos (\beta_1 - \kappa - \lambda) + \cos (\beta_2 - \kappa - \lambda) \right.$$
$$\left. + (e^{(\beta_1 - \beta_2 - \pi) \cot \lambda} - 1) \tan \lambda \sin (\beta_1 - \kappa - \lambda) \right\}$$

Since by the construction of the instrument $\xi$, $\zeta_1$, and $\zeta_2$ are small, the exponent of $e$ is practically equal to $-\pi \cot \lambda$. If $R = 200$ ohms and the coil makes 8 turns per second so that $\omega = 16\pi$ then, even if $L$ is so large as half a henry, $\pi \cot \lambda = \pi R / \omega L$ would amount to 25. Hence $e^{-\pi \cot \lambda}$ is negligible as compared with unity and the value of $q_1$, with a high degree of approximation may be written

$$q_1 = \frac{1}{R\omega} \left[ e_r (\pi + \beta_2 - \beta_1 - \tan \lambda) \right.$$
$$\left. + AF\omega \sin \gamma \{ \cos (\beta_1 - \kappa) + \cos \lambda \cos (\beta_2 - \kappa - \lambda) \} \right] \qquad (2)$$

Similarly, in the second phase the circuit is closed only while $\alpha$ varies from $\pi + \beta_2'$ to $2\pi + \beta_1'$, where $\beta_1' = \delta - \xi - \zeta_1$ and $\beta_2' = \delta + \xi + \zeta_2$; also $i_r = 0$ when $\alpha = \pi + \beta_2'$, and the thermal electromotive force, being determined by the brushes rather than by the commutator segments, is, at each break, reversed with

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reference to the coil. Imposing these conditions upon equation (1) we find for the current in the coil during the second phase

$$i_{r2} = -\frac{e_r}{R}\left\{1 - e^{(\pi+\beta_2'-\alpha)\cot\lambda}\right\}$$
$$+\frac{AF\omega}{R}\cos\lambda\sin\gamma\left\{\sin(\alpha-\kappa-\lambda) + e^{(\pi+\beta_2'-\alpha)\cot\lambda}\sin(\beta_2'-\kappa-\lambda)\right\}$$

But the galvanometer connections now are the reverse of what they were before, hence

$$q_2 = -\frac{1}{\omega}\int_{\pi+\beta_2'}^{2\pi+\beta_1'} i_{r2}\,d\alpha$$
$$= \frac{1}{R\omega}\Big[e_r(\pi+\beta_1'-\beta_2'-\tan\lambda)$$
$$+AF\omega\sin\gamma\{\cos\lambda\cos(\beta_1'-\kappa-\lambda)+\cos(\beta_2'-\kappa)\}\Big] \quad (3)$$

to the same order of approximation as in the preceding case (2).

The resultant quantity of electricity that passes in the positive direction through the galvanometer during each complete turn of the coil in the right-handed direction is obtained by adding (2) and (3). This sum can be put in the form

$$Q_r = q_1 + q_2$$
$$= \frac{2}{R\omega}\Big[e_r(\pi-\zeta_1-\zeta_2-\tan\lambda)$$
$$+AF\omega\sin\gamma\cos\lambda\{(P_c+P_c')\cos\kappa+(P_s-P_s')\sin\kappa\}\Big] \quad (4)$$

where

$$\left.\begin{aligned} P_c &= C\cos\xi\cos\delta - S\sin\xi\sin\delta \\ P_c' &= C'\cos\xi\sin\delta + S'\sin\xi\cos\delta \end{aligned}\right\} \quad (5)$$

$$\left.\begin{aligned} P_s &= C\cos\xi\sin\delta + S\sin\xi\cos\delta \\ P_s' &= C'\cos\xi\cos\delta - S'\sin\xi\sin\delta \end{aligned}\right\} \quad (6)$$

$$\left.\begin{aligned} C &= \cos\tfrac{1}{2}(\zeta_1-\zeta_2)\left[\cos\{\lambda+\tfrac{1}{2}(\zeta_1+\zeta_2)\}+\cos\tfrac{1}{2}(\zeta_1+\zeta_2)\sec\lambda\right] \\ C' &= \cos\tfrac{1}{2}(\zeta_1-\zeta_2)\cos\{\lambda+\tfrac{1}{2}(\zeta_1+\zeta_2)\}\tan\lambda \\ S &= \sin\tfrac{1}{2}(\zeta_1-\zeta_2)\left[\sin\{\lambda+\tfrac{1}{2}(\zeta_1+\zeta_2)\}+\sin\tfrac{1}{2}(\zeta_1+\zeta_2)\sec\lambda\right] \\ S' &= \sin\tfrac{1}{2}(\zeta_1-\zeta_2)\sin\{\lambda+\tfrac{1}{2}(\zeta_1+\zeta_2)\}\tan\lambda \end{aligned}\right\} \quad (7)$$

For a left-handed rotation of the coil $\alpha = -\omega t$ and the lag is of the same magnitude as before, but of the opposite sign with respect to $\alpha$. Hence, instead of (1) we have

$$i_l = \frac{e_1}{R} + k\,e^{\alpha\cot\lambda} - \frac{AF\omega}{R}\cos\lambda\sin\gamma\sin(\alpha-\kappa-\lambda) \quad (8)$$

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For a left-handed rotation the circuit is closed, during what we have called the first phase, while $\alpha$ varies from $\pi + \beta_2$ to $\beta_1$ and the current is zero when $\alpha$ has the first of these values. During the second phase the circuit is closed while $\alpha$ varies from $\beta_1'$ to $-\pi + \beta_2'$. Hence, proceeding in exactly the same way as before, the quantities of electricity which pass through the galvanometer in the positive direction, during the two phases of a left-handed rotation of the coil, are found to be

$$q_1 = \frac{1}{R\omega}\Big[e_l\,(\pi + \beta_2 - \beta_1 - \tan\lambda) - AF\omega\sin\gamma\,\{\cos\gamma\cos(\beta_1 - \kappa - \lambda) + \cos(\beta_2 - \kappa)\}\Big] \quad (9)$$

$$q_2 = \frac{1}{R\omega}\Big[e_l\,(\pi + \beta_2' - \beta_1' - \tan\lambda) - AF\omega\sin\gamma\,\{\cos(\beta_1' - \kappa) + \cos\gamma\cos(\beta_2' - \kappa - \lambda)\}\Big] \quad (10)$$

The total quantity for one turn of the coil is

$$\begin{aligned} Q_l &= q_1 + q_2 \\ &= \frac{2}{R\omega}\Big[e_l\,(\pi - \zeta_1 - \zeta_2 - \tan\lambda) - AF\omega\sin\gamma\cos\lambda\,\{(P_c - P_c')\cos\kappa + (P_s + P')\sin\kappa\}\Big] \end{aligned} \quad (11)$$

where the various symbols have the same significance as in (4).

Hence from (4) and (11) it is evident that the amount of electricity that passes in the positive direction through the galvanometer per turn for a right-handed spin exceeds that for a left-handed spin by the amount

$$Q_r - Q_l = \frac{2}{R\omega}\Big[(e_r - e_l)\,(\pi - \zeta_1 - \zeta_2 - \tan\lambda) + 2AF\omega\sin\gamma\cos\lambda\,(P_c\cos\kappa + P_s\sin\kappa)\Big] \quad (12)$$

If not too great, the deflections of the galvanometer may be taken as proportional to $Q\omega/2\pi$, that is, to $Q$ if the speed has a fixed value. Hence, the galvanometer deflection will be independent of the direction of spin—that is, we shall have a balance—only when $Q_r - Q_l$ is zero. If the thermal electromotive force is independent of the direction of spin[3], this will occur when

$$\sin\gamma = 0 \quad (13)$$

or

$$\cot\kappa = -P_s / P_c \quad (14)$$

[3] This is not necessarily the case, though it is probably a very close approximation to the truth, and is probably the best assumption that can be made. By a construction of the instrument which allows the coil terminals to be reversed with respect to the commutator segments, the thermal effect can be eliminated from both $Q_r$ and $Q_l$ and so $Q_r - Q_l$ will have the same value as if $e_r$ were equal to $e_l$.

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By reference to (5), (6), and (7) it is seen that $P_s/P_c$ is a complicated expression unless the breaks are exactly 180° apart ($\xi=0$), or are of equal angular duration ($\zeta_1=\zeta_2$) so that $S=0$. Under either of these conditions (14) becomes

$$\cot \kappa = -\tan \delta \tag{15}$$

which states that $F$ lies in the mean plane of commutation.

The conditions for balance as expressed by (13) and (15) are exactly those found from purely physical considerations.

The ideal construction is such that $\xi$, $S$, and $\delta$ are all zero, so that (15) reduces to $\kappa=90°$. In general, however, none of these quantities will be zero. But, since $\delta$ is determined solely by the position of the brushes, it is possible to give it any value desired. Consequently, if $\delta$ is adjusted so that $P_s$ equals zero, the condition that $\kappa$ must be 90° for a balance is again secured. From (6) it is evident that $P_s$ will be zero if $\tan \delta = -(S/C) \tan \xi$; $S$ and $\xi$ being always small, and $C$ being scarcely less than 2, this requires that $\delta$ be a small angle, *i. e.*, the mean plane of commutation will very nearly coincide with the inclined plane of the instrument.

It now remains to find the relation between the inclination ($I_1$) of the axis of rotation, as given by the inclination circle when a balance is obtained, and the magnetic inclination $I$. If the instrument is perfectly constructed the axis of rotation will always lie in the meridional plane of the instrument and its angular coordinates will be ($\theta'$, 0). In Fig. 5 let $OA$ be the direction of the axis of rotation, $OB$ be that of $F$, and $OP$ be the polar axis. The coordinates of $B$ are ($\theta''$, $\phi''$) and the angle $BAP$ is $\kappa$. Hence

$$\cot \kappa = \frac{\cos \theta' \cos \phi'' - \sin \theta' \cot \theta''}{\sin \phi''}$$

For a balance cot $\kappa$ must be zero, and, therefore,

$$\cot \theta'' = \cot \theta' \cos \phi''$$

If the inclination axis is horizontal, $\theta''=90° - I$; $\theta'=90° - I_1$, and $\phi''$ is the negative magnetic azimuth of the meridional plane of the instrument. Consequently when a balance ($Q_r=Q_l$) is obtained

$$\tan I = \tan I_1 \cos \phi''$$

Hence, in every case the condition for a balance, as defined in this paper, is simply that the axis of rotation of the coil shall have the

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direction that would be taken by a perfect dip needle when its pivots are placed parallel to the inclination axis of the earth inductor.

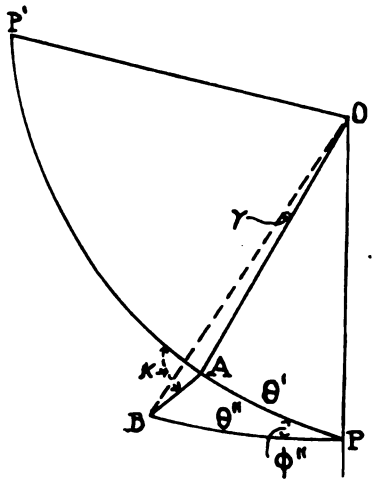


FIG. 5.

*Adjustment of Brushes.*—When it is possible to determine the magnetic meridian with the necessary accuracy, the adjustment of the brushes so as to make $P_s = 0$ may be made as follows:

Place the axis of rotation vertical and turn the instrument in azimuth by 90° from the magnetic meridian so that the inclined plane of the instrument will coincide with the magnetic meridional plane. Under these conditions $\gamma$ will be the complement of the inclination ($I$) and $\kappa$ will be 90°. Hence, if $e_r = e_l$, or if the thermal effect has been eliminated from both $Q_r$ and $Q_l$, the general expression (12) becomes

$$Q_r - Q_l = 4\frac{AF}{R}\cos I \,.\, \cos\lambda \,.\, P_s.$$

Hence, if the positions of the brushes are now shifted until the deflection of the galvanometer is independent of the direction of spin, *i. e.*, $Q = Q_l$, then $P_s$ must be zero, and the desired adjustment will have been secured.

Since the value of $P_s$ depends solely upon the construction of the instrument, upon the adjustment of the brushes, and upon the lag, it is evident that the above adjustment having once been made will continue so long as the same electrical circuit and the

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same speed are used and the brushes and the commutator remain unchanged.

*Effect of Inconstant Speed.*—It is evident that an absolutely uniform speed can not be maintained. It, therefore, becomes necessary to determine the degree of uniformity required. This involves a knowledge of the variation of the thermal electromotive force with the speed; since, however, this electromotive force is in general small, it will suffice to assume that it is proportional to the angular velocity.

If the thermal current is negligible, or proportional to the angular velocity of the coil, the general equations (4, 11) show that the galvanometer deflection for a given setting of the coil is proportional to the angular velocity, if the lag is small. Consequently the speed should be maintained uniform to the same order of accuracy as it is desired to determine the deflection of the galvanometer. For example, if the accuracy desired allows an uncertainty of 0.5 mm. in the deflection of the galvanometer, and if, when balance ($Q_r = Q_t$) is attained, the deflection is 5 mm., then the speed should be maintained constant to an accuracy of 10%: if the deflection were 1mm., an accuracy of 50% would be sufficient. This is the accuracy with which the speed must be the same for the two directions of spin. For either direction alone the range may be greater than this, provided it averages to the desired speed to this order of accuracy, and provided the oscillations of the galvanometer are sufficiently small for the observer to determine the mean deflection to the required order of accuracy.

*Error Produced by Setting for Zero Deflection.*—As it has been customary, when taking observations with the rotation axis of the coil in the magnetic meridional plane, to make no attempt to maintain a constant speed, to adjust to a zero deflection, and to take the mean of the observations thus found for the two directions of the spin, it is desirable to study the possible error thus introduced. It is also desirable to consider briefly the use of this method when, by accident, or otherwise, the axis of rotation does not lie in the meridional plane.

Assume that the instrument is perfectly constructed. Then from Fig. 5 it is evident that

$$\begin{aligned} \sin\gamma \sin\kappa &= \sin\theta'' \sin\phi'' \\ \sin\gamma \cos\kappa &= \cos\theta' \sin\theta'' \cos\phi'' - \sin\theta' \cos\theta'' \end{aligned} \qquad (16)$$

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When these values are substituted in the general equations (4, 11), it is found that zero deflections will result when

$$\cos\theta_r'\sin\theta''\cos\phi'' - \sin\theta_r'\cos\theta'' + \left\{\frac{P_s - P_s'}{P_c + P_c'}\right\}_r \sin\theta''\sin\phi'' = \frac{-e_r(\pi - \zeta_1 - \zeta_2 - \tan\lambda_r)}{AF\omega_r(P_c + P_c')_r\cos\lambda_r}$$

$$\cos\theta_l'\sin\theta''\cos\phi'' - \sin\theta_l'\cos\theta'' + \left\{\frac{P_s + P_s'}{P_c - P_c'}\right\}_l \sin\theta''\sin\phi'' = \frac{e_l(\pi - \zeta_1 - \zeta_2 - \tan\lambda_l)}{AF\omega_l(P_c - P_c')_l\cos\lambda_l}$$

In order that the mean of $\theta_r'$ and $\theta_l'$ shall equal $\theta''$ when observations are taken with the axis of the coil in the magnetic meridional plane ($\phi''=0$), it is necessary that the two right hand members be equal in magnitude and of opposite signs. In general these conditions will be satisfied only for $e_r=e_l=0$, which requires $\theta_r'=\theta_l'=\theta''$.

If, however, the breaks are of equal duration ($\zeta_1=\zeta_2$), so that the values of $S$ and of $S'$ (7) reduce to zero, or if the breaks are exactly 180° apart ($\xi=0$), and if, in addition to one or other of the preceding, $\delta=0$, then $P_c'=0$. If in addition to this, the speed is the same in the two cases, and $e_r$ and $e_l$ are equal, then the mean of $\theta_r'$ and $\theta_l'$ will again be equal to $\theta''$.

It is evident from the above expressions that, *if the speed is not the same in the two cases, then the mean of $\theta_r'$ and $\theta_l'$ will, in general, not be equal to $\theta''$.*

The results obtained by this procedure have been, in general, satisfactory because $e_r$, $e_l$, $\xi$, and $\delta$ are, as a rule, very small, so that any difference existing in practice between the two speeds can produce but a small absolute effect. The value of the thermal electromotive force may, however, be large; hence, *when the highest precision is desired, it is not safe to trust to this method even when working in the meridian,* although the error thus induced will usually be small.

For exmeridian observations ($\phi''$ not zero) the mean of $\theta_r'$ and $\theta_l'$ will not be related to $\theta''$ and $\phi''$ in a simple manner unless the right members and the last terms in the left members of the above equation are respectively equal in magnitude, and of opposite signs. When this is the case the sum of the two equations gives the equality

$$-\cot\theta'' = \cot\frac{1}{2}(\theta_r' + \theta_l')\cos\phi''$$



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The conditions under which the right hand members are thus related have just been considered.

Usually $S$, $\xi$, and $\delta$ are very small; if they are equal to zero, it is evident from (5), (6), (7) that $P_s$ and $P_c{}^1$ are zero, and that $P_c$ and $P_s'$ are equal to $C$ and to $C'$ respectively. For small values of $\lambda$, $C$ varies but slowly with the lag, and $C'$ is proportional to the lag. Under these conditions the coefficients of the last terms in the left members of the equations are very nearly proportional to $-\lambda$ and to $+\lambda$ respectively; and these terms will be equal in magnitude and of opposite signs when the speeds are the same for the two cases. If the two speeds are not the same, or if the above conditions are not fulfilled, then these terms can not be equal in magnitude and of opposite signs unless $\theta''=0$, *i. e.*, at the magnetic poles, or $\phi''=0$, except for a special ratio between the two speeds.

Since the value of the coefficient of the term in sin $\phi''$ is a function of the speed, it is evident that, for a given setting, a zero deflection can be obtained for but a single speed, unless $\theta''$ or $\phi''$ are so small as to reduce the magnitude of this term below the limit of observation. Hence, *for exmeridian observations, a knowledge of the settings at which the deflection is zero for the two directions of spin is, in general, of no value for the determination of $\theta''$, unless it is known that they were obtained at the same speed of rotation.* Even when the speed is the same in both cases, the simple relation given will not be exactly satisfied unless all the conditions specified have been fulfilled. *It is therefore not desirable, when the highest accuracy is sought, to adjust the settings for zero deflections.* The setting for which the observed deflection is independent of the direction of spin does, however, exactly satisfy the simple relation given above, whenever $e_r=e_l$ and the brushes have been set in the manner already specified.

## Errors Caused by Maladjustments.

In case the instrument is not perfectly constructed, or is improperly set up, $\theta''$ and $\phi''$ will not be so simply related to the true inclination and to the magnetic azimuth, and the value of the inclination calculated on the assumption that the instrument is perfect in construction and in adjustment will differ from the true inclination. The errors thus produced in the calculated inclination we shall call errors of maladjustment; they are identically the same as these maladjustments would produce in the

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case of a massless dip-needle with perfect pivots. We shall assume them to be small so that their products and powers higher than the first can be neglected, and that each error can be calculated as though it existed alone. For each type of maladjustment, two cases must be considered: 1. Its effect upon single exmeridian observations, *i. e.*, such as are made with but a single azimuth setting of the instrument. From such observations the inclination is deduced by means of the relation

$$\cot I_1 = \cot I \cos \phi \tag{17}$$

This involves an exact knowledge of the magnetic azimuth. 2. Its effect upon double exmeridian observations, *i. e.*, such as are made at two azimuths differing by 90° and lying on opposite sides of the magnetic meridian. From such observations the inclination is deduced by means of the relation

$$\cot^2 I = \cot^2 I_1 + \cot^2 I_2 \tag{18}$$

This involves no exact knowledge of the magnetic azimuth. For each type of maladjustment the errors will be considered in the order given above; the resulting error in the first case will be denoted by $\eta_1$, and that in the second case by $\eta_2$.

Neglecting circle errors, such as eccentricity and errors of graduation, there are six main errors to be considered: 1. The axis of rotation of the coil is not perpendicular to the inclination axis; 2. The inclination axis is not perpendicular to the azimuth axis; 3. The azimuth axis is in the plane of the magnetic prime vertical, but is not vertical; 4. The azimuth axis is in the meridional plane, but is not vertical; 5. The error in reading the azimuth circle; 6. The error in reading the inclination circle.

1. *Axis of rotation of coil not perpendicular to inclination axis.* If the instrument is perfect in other respects, but the north end of the axis of rotation makes an angle of $90° - \epsilon$ with the east end of the inclination axis, then as the inclination of the rotation axis is altered the latter will trace out, on the sphere of reference, a small circle lying in a plane parallel to the meridional plane of the instrument. Hence, the condition for an exmeridian balance, namely, that the plane including the axis of rotation and the direction of the total magnetic intensity, $F$, shall be perpendicular to the meridional plane of the instrument, involves the condition that it shall also be perpendicular to the plane of the small circle spoken of above. The latter condition is, however, the one that makes the angle $\gamma$ a minimum. Hence, as before, the sole condition required for a balance is that $\gamma$ be a minimum.

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If in Fig. 6 $OB$ be the direction of $F$, the coordinates of $B$ being $(\theta'', \phi'')$, $OA$ be the direction of the axis of rotation, the coordinates of $A$ being $(\theta', \phi')$, and $OE$ be the intersection of the plane $BOA$ with the meridional plane, the coordinates of $E$ being $(\theta, 0)$; then

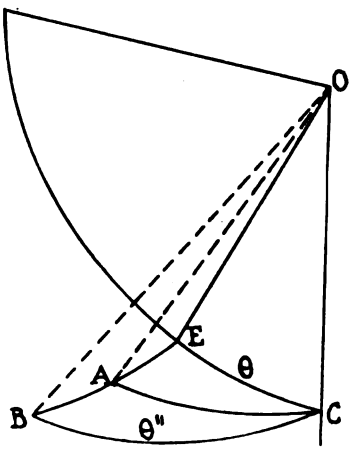


FIG. 6.

the condition for balance is that the angle $\kappa = BEC = 90°$. Hence, $AE = \epsilon$ and

$$\tan \theta = \tan \theta'' \cos \phi''$$

If the instrument is properly leveled, $\theta'' = \frac{\pi}{2} - I$, $\theta = \frac{\pi}{2} - I_1$, and we find our original equation

$$\cot I_1 = \cot I \cos \phi''$$

It is obvious that this maladjustment will produce no error when a galvanometer is used. But it should be noted that, when $\phi'' = 0$, the balance will not correspond to a zero induced current, but will be of the kind met with in usual exmeridian observations; that is, merely the integral of the induced current which passes through the galvanometer will be zero. If the commutator were replaced by slip rings, and a telephone receiver were used as a detector, zero sound would be obtained only when $\gamma = 0$, *i. e.*, when the instrument is oriented in azimuth by the angle $-\phi''$ where $\phi''$ is defined by the relation

$$\sin \phi'' = \frac{\sin \epsilon}{\sin \theta''} = \frac{\sin \epsilon}{\cos I}$$

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At the magnetic equator $\phi'' = \epsilon$; as we proceed to higher latitudes it increases, becomes 90° where $I = 90° - \epsilon$, and for still higher latitudes no balance can be obtained. On substituting this value of $\phi''$ in the above expression for balance, it is found that the observed inclination will be

$$\cot I_1 = \frac{\cot I \sqrt{\cos^2 I - \sin^2 \epsilon}}{\cos I} = \frac{\sqrt{\cos^2 I - \sin^2 \epsilon}}{\sin I}$$

$$\frac{1}{\sin^2 I_1} = \frac{1 - \sin^2 \epsilon}{\sin^2 I}$$

Hence, $\sin I_1 = \sin I \sec \epsilon$

It is thus seen that the observed value ($I_1$) of the inclination will not be the true value ($I$). Expanding[4] $I_1$ by Maclaurin's theorem gives

$$I_1 = I + 0.5\epsilon^2 \tan I + \ldots$$

Hence the observed inclination exceeds the true by an amount

$$\eta_1 = 0.5\ \epsilon^2 \tan I + \ldots \qquad (19)$$

This error increases rapidly with $I$, is independent of the sign of $\epsilon$, and changes sign when $I$ changes sign. Consequently $I_1$ always numerically exceeds $I$. In Table IV are to be found the values of $-\eta_1$, which correspond to certain values of $I$ and of $\epsilon$.

2. *The inclination axis not perpendicular to the azimuth axis.* It is always possible to set the azimuth axis vertical to within a small angle, determined solely by the sensibility of the level at command and the stability of the instrument. Assume that it is placed strictly vertical and that, owing to an error in construction, the east end of the inclination axis makes an angle of $90° - \epsilon$ with the polar or azimuth axis. As the instrument is rotated about its azimuth axis, the radius vector, which lies in the prime vertical of the sphere of reference and is perpendicular to the inclination axis, describes about the polar axis of the sphere a cone of half angle $\epsilon$, and lies in the plane of the magnetic prime vertical when the inclination axis does the same.

[4] If desired the error in this and in the following cases may be determined by a direct trigonometric expansion, as follows: The value of the inclination ($I_c$) which is computed from the observations on the assumption that $\epsilon$ is zero (in this case $I_c = I_1$) exceeds the true value by an amount $\eta_1$ to be determined. In the equation connecting $I_c$, $I_1$, $I$, and $\epsilon$ replace $I_c$ by its value $I + \eta_1$ and solve for $\eta_1$. In the present case, this gives $\sin (I + \eta_1) = \sin I \sec \epsilon$, or $\sin \eta_1 = \tan I (\sec \epsilon - \cos \eta_1)$. If $\eta_1$ and $\epsilon$ are small, a first approximation gives $\eta_1 = \tan I (\sec \epsilon - 1) = 0.5\ \epsilon^2 \tan I$. For a second approximation, retain the next term in the expression of $\sec \epsilon$, and replace $\cos \eta_1$ by $(1 - 0.5\ \eta_1^2)$ in which $\eta_1$ is given the value found by the first approximation.

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In Fig. 7 let $OP$ be the azimuth axis, $ON$ be the direction of the radius vector just defined, $OA$ be the direction of the axis of rotation, $OB$ be that of the Earth's total magnetic intensity, $F$, the plane $OPD$ be that of the magnetic prime vertical, and the plane $OPD'$ be that of the prime vertical of the sphere of reference.

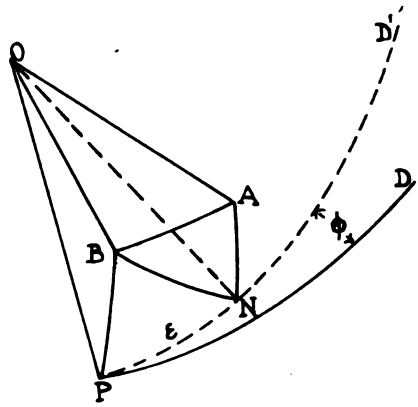


FIG. 7.

By this construction $BPD$ and $ANP$ are right angles; $BAN$ is the angle designated as $\kappa$, and the angle $D'PD=\phi$ is the azimuth setting of the instrument, measured from north to east. The angular arc $PN$ is $\epsilon$, $AN$ is $90°-I_1$, and $BP$ is $90°-I$.

For balance $\kappa$ must be 90°, hence the triangle $BAN$ has a right angle at $A$; accordingly

$$\cos ANB = \tan AN \cot BN = \cot I_1 \cot BN$$
$$= \sin BNP = \frac{\sin BP}{\sin BN} \sin BPN = \frac{\cos I \cos \phi}{\sin BN}$$

Whence $\cos I \cos \phi = \cot I_1 \cos BN$
$$= \cot I_1 (\cos BP \cos PN + \sin BP \sin PN \cos BPN)$$
$$= \cot I_1 (\sin I \cos \epsilon + \cos I \sin \epsilon \sin \phi) \qquad (20)$$

Hence the computed inclination ($I_c$) is related to the true inclination as shown by the equation

$$\tan I_c \equiv \tan I_1 \cos \phi = \tan I \cos \epsilon + \sin \epsilon \sin \phi$$

On expanding, it is found that

$$I_c = I + \epsilon \cos^2 I \sin \phi - 0.25\, \epsilon^2 \sin 2I\, (1 + 2 \sin \phi) + \ldots$$

Therefore the computed exceeds the true value by the amount

$$\eta_1 = \epsilon \cos^2 I \sin \phi - 0.25\, \epsilon^2 \sin 2I\, (1 + 2 \sin \phi) + \ldots \qquad (21)$$

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For small values of $\epsilon$, the second term is negligible as compared with the first, except for very small values of $\phi$. For $\phi$ equal to zero the error is independent of the sign of $\epsilon$, and changes sign with $I$. It follows that when $\phi$ is zero, or 180°, the computed value of the inclination is always numerically smaller than the true value.

When $\phi$ is not very near to zero, or to 180°, the first term is the important one. It shows that the error changes sign with both $\epsilon$ and $\phi$, but does not change sign with $I$. Consequently, in this case, for positive values of the product $\epsilon \sin \phi$ the computed inclination algebraically exceeds the true value. For negative values of the product the reverse is the case. Whence it is evident that, for any small value of $\epsilon$, and for values of $\phi$ that are not too near to zero or to 180°, this error can be eliminated by taking the mean of the values computed for observations taken at two azimuths differing by 180°. Values of $\eta_1$, in minutes, corresponding to certain values of $\epsilon$, $\phi$ , and $I$ will be found in Table I.

If $I_1$ and $I_2$ are the observed inclinations for two azimuths differing by 90°, one being positive and the other negative, each will satisfy an equation of the form (20) just deduced from geometrical considerations. If $\epsilon$ is small, and if $I$ is not too small, these equations may be put in the form

$$\cot I_1 = \cot I \cos \phi \{1 - \epsilon \sin \phi \cot I + 0.5 \epsilon^2 (1 + 2 \sin^2 \phi \cot^2 I) + \ldots\}$$
$$\cot I_2 = \cot I \sin \phi \{1 + \epsilon \cos \phi \cot I + 0.5 \epsilon^2 (1 + 2 \cos^2 \phi \cot^2 I) + \ldots\}$$

Whence
$$\cot^2 I_c = \cot^2 I_1 + \cot^2 I_2$$
$$= \cot^2 I \{1 - \epsilon \cot I \sin 2\phi (\cos \phi - \sin \phi) + \epsilon^2 (1 + 1.5 \cot^2 I \sin^2 2\phi) + \ldots\}$$

On expanding it is found that

$$\eta_2 = I_c - I = \sqrt{0.5}\, \epsilon \cos^2 I \sin 2\phi \sin (0.25\pi - \phi)$$
$$- \left(\frac{\epsilon^2}{8}\right) \sin 2I [2 + \cot^2 I \sin^2 \phi \{3 - 0.5 (1 + 2 \cos^2 I) (1 - \sin 2\phi)\}] + \ldots \quad (22)$$

The presence of $\cot^2 I$ in the second term makes it evident that this expression for $\eta_2$ will not be valid for very small values of $I$. For other values of $I$ it is a rapidly convergent series, and it shows that, at the magnetic poles and also for $\phi$ equal to zero, to 45°, or to 90°, the error $(\eta_2)$ is proportional to $\epsilon^2$, and consequently is very small. In no case can it be very large. The error represented by the first term does not change sign with $I$, consequently it represents the amount by which $I_c$ algebraically exceeds $I$; it can be completely eliminated by using the mean of observations taken in azimuths which differ by 180°.

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For the special case of $I$ equal to zero, *i. e.*, at the magnetic equator, the equation (20) geometrically established at the beginning of this section becomes

$$\tan I_1 = \sin \epsilon \tan \phi$$

The corresponding equation for $I_2$ is

$$\tan I_2 = -\sin \epsilon \cot \phi$$

Whence $\cot^2 I_c = \cot^2 I_1 + \cot^2 I_2 = \csc^2 \epsilon (\cot^2 \phi + \tan^2 \phi)$

and

$$\eta_2 = I_c = \sin \epsilon (\cot^2 \phi + \tan^2 \phi)^{-\frac{1}{2}}$$
$$= 0.5 \epsilon \sin 2\phi (1 - 0.5 \sin^2 2\phi)^{-\frac{1}{2}} \quad (23)$$

Thus at the magnetic equator, the error is zero for $\phi = 0$, or 90°, and is a maximum for $\phi = 45°$; it can be eliminated by using the mean of observations[5] taken in azimuths which differ by 180°. Values of $\eta_2$ for special values of the other quantities will be found in Table II.

3. *Azimuth axis inclined to the magnetic west.* Suppose the azimuth axis is strictly perpendicular to the inclination axis, but that its lower end is inclined to the magnetic west by an angle $\epsilon$. In Fig. 8 let $OP$ be the azimuth axis, $OA$ be the direction of the

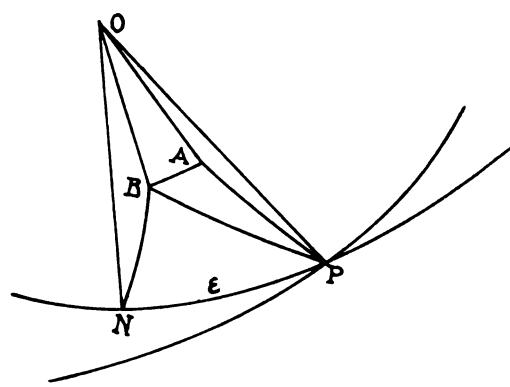


FIG. 8. *The direction of the Earth's field is OB, of the axis of rotation is OA, of the azimuth axis is OP, and of the true vertical is ON. The prime vertical plane of the instrument is PON. The arc PB is $\theta''$, PA is $\theta' = 90° - I_1$, BN is $90° - I$; the angle BNP is 90°, APN is $90° - \phi$, BPN is $90° - \phi''$.*

[5] Since the instrumental inclinations are measured from a fixed point on the inclination circle to the north end of the axis of rotation, it is evident that, if $I_1$ is the instrumental inclination corresponding to the azimuth $\phi$, and $I_1'$ is that corresponding to $\phi + 180°$, then $I_1'$ will be very nearly the supplement of $I_1$. Hence, in the reduction the mean of $I_1$ and of $180° - I_1'$ must be taken. The equation $\tan I_1 = \sin \epsilon \tan \phi$ shows that $\tan I_1$ and $\tan I_1'$ are equal, hence $I_1' = 180° + I_1$.

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axis of rotation, $OB$ that of the Earth's total magnetic force, $F$, $ON$ the true vertical, and the plane $ONP$ that of the prime vertical. By this construction $BN=90°-I$, $AP=90°-I_1$, $NP=\epsilon$, $BAP=\kappa$, $BNP=90°$, and $APN=90°-\phi$. When a balance has been secured $\kappa=90°$, and the following relations exist

$$\cos APB = \cot BP \tan AP$$
$$\cos BP = \cos BN \cos NP$$
$$\sin BPN = \sin BN \csc BP$$
$$\cos BPN = \cot BP \tan \epsilon$$

Whence $$\sin I \cos \epsilon \cot I_1 = \sin \epsilon \sin I \sin \phi + \cos I \cos \phi$$

or $$\cot I_c \equiv \cot I_1 \sec \phi = \tan \epsilon \tan \phi + \cot I \sec \epsilon \qquad (24)$$

On expanding it is found that

$$\eta_1 = I_c - I = -\epsilon \sin^2 I \tan\phi + 0.25\epsilon^2 \sin 2I (2\sin^2 I \tan^2\phi - 1) + \ldots \qquad (25)$$

As in the preceding case, when $\phi$ is zero, the error is very small and changes sign with $I$; hence, for this value of $\phi$, the true inclination ($I$) always numerically exceeds the computed value ($I_c$). For other values of $\phi$ the first term is the most important. This term does not change sign with $I$ but does with $\phi$; consequently, for small values of $\epsilon$, and for values of $\phi$ that are not too small, the true inclination algebraically exceeds the computed when $\epsilon \tan \phi$ is positive. This error can not be eliminated by using the mean of the observations made at two values of $\phi$ differing by 180°. The error increases rapidly with $\phi$. In Table III are given the values of $\eta_1$, which correspond to certain values of the other quantities.

If observations are taken at two azimuths differing by 90° and lying on opposite signs of the meridian, each will satisfy an equation of the form (24) just obtained trigonometrically. These equations may be put in the following forms:

$$\cot I_1 = (\cot I \cos \phi + \sin \epsilon \sin \phi) \sec \epsilon$$
$$\cot I_2 = (\cot I \sin \phi - \sin \epsilon \cos \phi) \sec \epsilon$$

and the computed inclination will be given by the relation

$$\cot^2 I_c = \cot^2 I_1 + \cot^2 I_2$$
$$= (\cot^2 I + \sin^2 \epsilon) \sec^2 \epsilon$$

Whence $$\eta_2 = I_c - I = -0.5\, \epsilon^2 \tan I + \ldots \qquad (26)$$

This error is zero at the magnetic equator, and is very small except near the magnetic poles. It can not be eliminated by using the



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mean of observations taken at azimuths differing by 180°. The true inclination ($I$) always numerically exceeds the computed value ($I_c$). For values of $\eta_2$ see Table IV.

4. *Azimuth axis inclined to the magnetic north.* Suppose that the azimuth axis is strictly perpendicular to the inclination axis and that its lower end is inclined to the magnetic north by an angle $\epsilon$. This differs from the case represented by Fig. 8 only in the fact that now the azimuth axis, $OP$, lies in the plane $OBN$. Accordingly $\theta'' = \pi/2 - I - \epsilon$, and $-\phi'' = \phi$, the magnetic azimuth of the plane $OAP$, hence for balance

$$\tan \theta' = \tan \theta'' \cos \phi''$$

or

$$\cot I_1 = \cot (I + \epsilon) \cos \phi$$

The computed inclination, however, is given by the relation

$$\tan I_c = \tan I_1 \cos \phi$$

Therefore

$$\eta = I_c - I = \epsilon \qquad (27)$$

Obviously the same is true for double exmeridian observations. This error can not be eliminated by combining observations taken at two values of $\phi$ differing by 180°.

5. *Errors in azimuth. Single exmeridian observations.* If, owing to a maladjustment, or to an error in the reading of the azimuth circle, the assumed magnetic azimuth of the axis of rotation of the coil exceeds its correct value ($\phi$) by an angle $\epsilon$, then the computed value ($I_c$) will be in error. The relation between the true and the computed inclination is given by the equations

$$\tan I = \tan I_1 \cos \phi$$

$$\tan I_c = \tan I_1 \cos (\phi + \epsilon)$$

Whence

$$\tan I_c = \tan I \sec \phi \cos (\phi + \epsilon)$$

and

$$\eta_1 = I_c - I = -0.5 \sin 2I \, [\epsilon \tan \phi + 0.5 \epsilon^2 (1 + 2 \sin^2 I \tan^2 \phi) + \ldots] \qquad (28)$$

The numerical value of this error is zero both at the poles and at the equator, and is a maximum for $I$ equal to 45°; it is very small for $\phi$ equal to zero, and increases rapidly with $\phi$. The error changes sign with $I$; for positive values of $\epsilon \tan \phi$ the true inclination always numerically exceeds the computed value. This error can not be eliminated by taking the mean of the results obtained at two azimuths differing by 180°. For special values see Table V.

*Double exmeridian observations.* Occasionally, and especially in the neighborhood of the magnetic poles, the magnetic inclina-

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tion is calculated from two observations taken at azimuths differing by 90°, one being to the east and the other to the west of the magnetic meridian. If the two observed inclinations are denoted by $I_1$ and by $I_2$, then the computed inclination ($I_c$) is derived by means of the relation

$$\cot^2 I_c = \cot^2 I_1 + \cot^2 I_2$$

Owing to errors, the two observations will actually be taken at azimuths which do not differ by exactly 90°, but by $90° + \epsilon$, and consequently the computed will differ from the true value.

Let the magnetic azimuth for the observed value $I_1$ be $\phi$, assumed positive; then, by hypothesis, that for $I_2$ will be $\phi - (90° + \epsilon)$. Whence

$$\cot I_1 = \cot I \cos \phi$$
$$\cot I_2 = \cot I \sin (\phi - \epsilon)$$
$$\cot^2 I_c = \cot^2 I \{\cos^2 \phi + \sin^2 (\phi - \epsilon)\}$$

Hence $\eta_2 = I_c - I = 0.25 \sin 2I \sin 2\phi \Big[\epsilon$

$$+ 0.25\,\epsilon^2 \{1 + 2\cos^2 I - 4 \cot 2\phi\} + \ldots\Big] \quad (29)$$

At the magnetic equator and at the magnetic poles the error is zero; for small values of $\phi$ it is very small, being proportional to the square of $\epsilon$. The error changes sign with $I$; consequently, if $\epsilon$ is small, the computed inclination always numerically exceeds the true when $\epsilon$ is positive; $\phi$ is positive by definition. Since $\epsilon$ is due to an error, it will scarcely be possible to obtain two more observations at azimuths differing from the former by exactly 180°; even were this possible, the error could not be eliminated by using the mean of the observations taken at azimuths differing by this amount. From Table VI it is evident that if the numerically smaller value of $\phi$ is so great as 10°, then an error of 6′ in the azimuthal difference will produce an error in the computed inclination that will exceed 0.1′ unless the inclination is less than 5° or greater than 85°.

*Observations at azimuths differing by 180°.* It is a common practice to eliminate any error in the direct determination of the nadir point of the inclination circle, and frequently to eliminate all direct determination of this point, by combining observations taken at azimuths which differ by 180°. If this difference is exactly 180°, and if the azimuth axis is vertical, it is obvious that the lower arc of the inclination circle included between these two

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readings is exactly twice the complement of the instrumental inclination; and the nadir point is at the center of this arc. If, however, owing to an error, the azimuth difference exceeds 180° by an angle $\epsilon$, the nadir point will not lie at the middle of the lower arc; and the difference in the two readings, measured through the nadir, will not be twice the complement of the inclination corresponding to the first reading. This difference, nevertheless, will always be the supplement of the numerical sum of the two inclinations, neither of which, however, can be separately known without a knowledge of the nadir point of the circle.

From these observations the inclination is computed on the assumption that $\epsilon$ is zero. Thus a false value is obtained. Let $I_1$ be the correct instrumental inclination corresponding to the azimuth $\phi$, and $I_2$ be the numerical value of the same quantity which corresponds to the azimuth $\phi + 180° + \epsilon$; as before, let $I$ denote the true inclination, and $I_c$ be the computed value. Then

$$\tan I = \tan I_1 \cos \phi = \tan I_2 \cos (\phi + \epsilon)$$
$$\tan I_c = \tan 0.5\ (I_1 + I_2) \cos \phi$$

In these equations, $I_1$, $I$, and $\phi$ are fixed by the location and by the first setting of the instrument, $I$ and $I_2$ are functions of the error $\epsilon$. On expanding $I_c$ it is found that

$$\eta = I_c - I = 0.25 \sin 2I \tan \phi \left[\epsilon + 0.5\,\epsilon^2 \{\cos^2 I \tan \phi + 2 \sec^2 I \csc 2\phi\,(1 + \tan^2 I \sec^2 \phi)^{-1}\} \ldots\right] \quad (30)$$

Unless $\epsilon \tan \phi$ is large, the second term is negligible as compared with the first; for example, if $\epsilon = 6'$ and $\phi = 80°$, the second term will never amount to more than about 0.″01; as $\phi$ increases above 80°, however, this term rapidly increases in importance. Excepting for sign, the first term is exactly one-half of the first term in the correction (28) found, in the first part of this section, for single exmeridian observations. Since within the limits of the table the second term is ineffective, the values of $\eta$ for this error may be taken as $-0.5$ times the value given in Table V.

6. *Error in reading the inclination circle.* We have assumed that the reading of the inclination circle of the instrument gives us the angle between the instrumental prime vertical and the inclined plane of the instrument. This will be true only when the reading of the circle which corresponds to the coincidence of

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these planes is known. The coincidence of the two planes may be determined by means of a level attached to the inclined plane. Or a balance may be obtained for two azimuths differing by 180°; the prime vertical *of the instrument* bisects the angle between these two positions of the inclined plane.

An error in the verticality of the instrumental prime vertical produces an equal error in the computed inclination ($I_c$); an error in the reading of the inclination circle produces an exactly equal error in the observed inclination ($I_1$). Let this error be $\epsilon$ and in such a direction that the observed inclination ($I_1$) is algebraically too great when $\phi$ is less than 90°. Then the computed inclination ($I_c$) will be given by the relation

$$\tan I_c = \tan I_1 \cos \phi$$

while $$\tan I = \tan (I_1 - \epsilon) \cos \phi$$

Then $$\tan I_c = \frac{\tan I + \tan \epsilon \cos \phi}{\cos \phi - \tan I \tan \epsilon} \cos \phi$$

Whence

$$\eta = I_c - I = \epsilon (\cos^2 I \cos \phi + \sin^2 I \sec \phi) + 0.5\, \epsilon^2 \sin 2I \cos^2 I \tan^2 \phi (\cos^2 \phi + \tan^2 I) + \ldots \quad (31)$$

if $\phi$ is less than 90°. This error increases rapidly with the departure from the meridian, especially in the vicinity of the magnetic poles. This error can not be eliminated by using the mean of two observations taken at azimuths differing by 180°. Values of $\eta$ for $\epsilon = 1.'0$ and for various values of $I$ and $\phi$ are given in Table VII.

## Use of Earth Inductor at Sea.

The amounts of electricity passing through the galvanometer for each half revolution are, by (4) and (11),

$$Q_r = \frac{2}{R\omega}\Big[e_r (\pi - \zeta_1 - \zeta_2 - \tan \lambda) + A F \omega \sin \gamma \cos \lambda \{(P_c + P_c') \cos \kappa + (P_s - P_s') \sin \kappa\}\Big]$$

$$Q_l = \frac{2}{R\omega}\Big[e_l (\pi - \zeta_1 - \zeta_2 - \tan \lambda) - A F \omega \sin \gamma \cos \lambda \{(P_c - P_c') \cos \kappa + (P_s + P_s') \sin \kappa\}\Big]$$

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Since the rate of rotation of the coil is rapid as compared with the period of the galvanometer or with any changes produced in the position of the instrument by the motion of the vessel or of the gimbals, we may, whenever the effects of the slower motion are of chief concern, replace the alternating current produced by the rotation of the coil by its equivalent continuous current. This will be proportional to $Q_r$ (or $Q_l$) and it will be here termed simply the "current."

A procedure by which $P_s$ can be made equal to zero was described on page 15, and it will be assumed that such an adjustment has been made. On introducing this condition into the equations, and on replacing $\gamma$ and $\kappa$ by their values (16) in terms of the adopted spherical coordinates, it is found that

$$Q_r = \frac{2}{R\omega}\Big[e_r(\pi - \zeta_1 - \zeta_2 - \tan\lambda) - A F\omega\cos\lambda\{(P_c + P_c')(\sin\theta'\cos\theta'' - \cos\theta'\sin\theta''\cos\phi'') + P_s'\sin\theta''\sin\phi''\}\Big]$$

$$Q_l = \frac{2}{R\omega}\Big[e_l(\pi - \zeta_1 - \zeta_2 - \tan\lambda) + A F\omega\cos\lambda\{(P_c - P_c')(\sin\theta'\cos\theta'' - \cos\theta'\sin\theta''\cos\phi'') - P_s'\sin\theta''\sin\phi''\}\Big]$$

Owing to the large error that may be produced in the inclination derived from exmeridian observations by a slight error in the azimuth, see (28), and because of the impossibility of holding the course of a ship with the necessary precision, it is, in general, impracticable to attempt to obtain exmeridian observations at sea.

Hence, it is attempted to make $\phi'' = 0$ and $\theta' = \theta''$ so that $Q_r$ and $Q_l$ are reduced to the purely thermal effects. However, owing to the motion of the vessel, $\phi''$ and $\theta''$ are continually varying within certain limits, so that, for a given setting of the coil, the current through the galvanometer will be continually changing, the rate of change being determined by the swinging of the gimbals and the yawing of the vessel. If the oscillations are periodic, the galvanometer will be forced to the same period, and the amplitude of its vibrations will be proportional to the amplitude of the oscillations of the current. This factor of proportionality will be small

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if the galvanometer is considerably damped and its period is not too near that of the oscillations of the inductor. Hence, by noting the turning points of the galvanometer swings, quantities proportional to the extreme values of $Q$ are obtained.

The only case of concern here is that in which $\phi''$ is small and $\theta' = \theta'' - \eta$, where $\eta$ is assumed small. The introduction of these values into the expressions for $Q_r$ and for $Q_l$ gives

$$Q_r = \frac{2}{R\,\omega}\Big[e_r\,(\pi - \zeta_1 - \zeta_2 - \tan\lambda) - A\,F\,\omega\cos\lambda\,\{(P_c + P_c')\,(0.25\,\phi''^2 \sin 2\,\theta'' - \eta) + P_s'\,\phi''\sin\theta''\}\Big] \quad (32)$$

and a similar expression for $Q_l$.

1. *Assume $\phi''$ zero.* Then the instrument is oscillating about a horizontal line in the magnetic prime vertical, and, if the mean value of $\theta''$ is equal to $\theta'$, $\eta$ will be alternately positive and negative, and, on the average, the magnitude of its positive value will equal that of its negative. Consequently, the mean deflection will be proportional to the first or thermal term of $Q_r$. The same will be true for the left-handed rotation; the condition that the mean deflection shall be independent of the direction of spin is again that of the ideal case, namely $\theta' = \theta''$, that is, $I_1 = I$.

2. *Oscillation about the vertical.* If the oscillations are periodic, and if the displacements are symmetrical with respect to the position $\phi'' = 0$, then the deflections produced by the $P_s'$ term are alternately positive and negative and, hence, their mean is zero. In order that the mean of the extreme values of the $P_c + P_c'$ term may vanish it is necessary that

$$\eta = I_1 - I = \frac{1}{8}\,\phi_m^2 \sin 2\,I \quad (33)$$

where $\phi_m$ is the extreme elongation of the oscillation. The observed value of the inclination always numerically exceeds the true value.

If $\phi''$ is not periodic, but varies more or less steadily, then its particular value ($\phi$) at the time of the observation must be considered. In this case the $(P_c + P_c')$ term can vanish only if $\eta = 0.25\,\phi^2 \sin 2\,I$. In this case the error is twice as large as that found for a periodic oscillation of elongation $\phi$. In Table VIII will be found the values of $\eta$ which correspond to certain values of $\phi_m$ and of $I$.

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3. *Oscillation about a horizontal line in the magnetic meridian.* If the inclination of the azimuth axis to the vertical is $\epsilon$, then the construction shown in Fig. 8 applies. Whence, if $\epsilon$ is small,

$$\cos \theta'' = (1 - 0.5\ \epsilon^2) \sin I$$
$$\sin \theta'' \cos \phi'' = \cos I$$
$$\sin \theta'' \sin \phi'' = \epsilon \sin I$$

Hence the value of $Q_r$ is given by the expression

$$Q_r = \frac{2}{R\,\omega}\Big[e_r\,(\pi - \zeta_1 - \zeta_2 - \tan \lambda) + A\,F\,\omega \cos \gamma \{(P_c + P_c')(\sin \theta' \sin I\,(1 - 0.5\,\epsilon^2) - \cos \theta' \cos I) - P_s'\,\epsilon \sin I\}\Big]$$

If the oscillations of the azimuth axis are symmetrical with respect to the vertical, then the mean galvanometer deflection corresponding to the $P_s'$ term is zero. That corresponding to the $(P_c + P_c')$ term, however, can not be zero unless

$$\cot \theta' = (1 - 0.25\ \epsilon^2) \tan I$$

$\theta'$ is the complement of the value $I_c$ which is inferred to be the true inclination; on expanding, it is found that

$$\eta = I_c - I = -\frac{\epsilon^2}{8} \sin 2\ I \qquad (34)$$

The error is of the same magnitude as in the previous case, but is of the opposite sign.

Hence, for marine work exactly the same procedure should be followed as for work on land, except that sufficient turning points of the galvanometer should be noted to obtain a good determination of the mean of the two readings. This mean takes the place of the steady reading obtained in land work. Except for errors in reading and of adjustment, the accuracy of the determination is limited solely by the closeness with which the vessel can be held to her course and by the oscillation of the instrument in the plane of the prime vertical. The magnitude of the errors thus produced can be determined by means of the expressions just deduced (33) and (34).

*Conclusions.*

1. To obtain the highest possible accuracy with an earth inductor it is necessary to work at a fixed speed of rotation of the coil and to interpolate to that reading of the inclination circle for

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which the galvanometer deflection is independent, in magnitude and direction, of the direction of spin; this setting is called the *setting for balance.*

2. When the position of the brushes has been adjusted as described on page 15, the direction of the axis of rotation for the balance setting is exactly that of a massless dip needle with perfect pivots and similarly adjusted in level and azimuth. The thermal electromotive force is assumed to be independent of the direction of spin.

3. When working in the manner just described, no error is introduced by the rotation axis not being perpendicular to the inclination axis.

4. If the inclination axis is not perpendicular to the azimuth axis an error, not exceeding the complement of the angle between the axes, may be produced. If the complement is small the error is completely eliminated by taking the mean of the results obtained for azimuths differing by exactly 180°.

5. If the instrument is out of level by a small rotation about a horizontal line in the magnetic meridional plane, large errors may be introduced in exmeridian observations. This error can not be eliminated by taking the mean of observations taken at azimuths differing by 180°. It increases rapidly on leaving the meridian and at 80° from the meridian an error in level of a single minute may produce an error of over 5′ in the inclination. If the inclination is obtained by combining, in the usual way (18), two observations taken at azimuths differing by 90°, the error is much less, practically zero if the error in level amounts to but a few minutes.

6. If the instrument is out of level by a small rotation about a horizontal line lying in the magnetic prime vertical, and if the inclination be determined from observations taken at azimuths which differ by exactly 180°, then the deduced inclination will be in error by the same amount as the instrument is out of level.

7. The inclination deduced (17) from observations taken at but a single azimuth will be in error if the assumed azimuth is incorrect. This error increases rapidly as the meridian is left, and at 80° an error of 6′ in the azimuth may produce an error of 17′ in the inclination.

8. The inclination deduced (18) from observations taken at two azimuths supposed to differ by 90° will be in error if the azimuthal difference is not exactly 90°; if it differs from 90° by 6′ the calculated inclination may be in error by 1.′5.



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9. The inclination deduced from observations taken at two azimuths supposed to differ by 180° will be in error if the azimuthal difference is not exactly that assumed. This error increases rapidly as the meridian is left, and, at an azimuth of 80°, an error of 6′ in the azimuthal difference may produce an error of 8.′5 in the inclination.

10. An error in reading the inclination circle, or in the determination of its nadir point, produces an error in the deduced inclination. This error increases rapidly on leaving the meridian, and at 80° an error of 1.′0 may produce an error of 6.′0 in the calculated inclination.

11. Theoretically, marine work differs from work on land solely in that exmeridian observations are, in general, impracticable, and in that the mean of the turning points of the galvanometer must be used. The oscillations of the instrument about a vertical axis, or about a horizontal one lying in the meridional plane, produce errors in the deduced inclination. If the oscillation is periodic and has a maximum elongation of 4°, the error may amount to 2′. If the displacement is not periodic, but more like a slow drift, then the error for a 4° displacement may be 4′.

12. All of these errors apply directly to a massless dip needle with perfect pivots.

## APPENDIX.

The following tables give the errors ( $\eta = I_c - I$ ) that are produced in the computed inclination by an error ($\epsilon$) in the adjustment. They are given for the purpose of showing the accuracy of adjustment that must be secured in any case in order to obtain a given accuracy in the result, rather than for the purpose of enabling one to correct a result obtained under conditions of maladjustment. Looked at in another way, the tables give information regarding the uncertainty that attaches to results obtained under given conditions, when the limit of precision of adjustment is known.

The value of $\eta$ in terms of $\epsilon$, and the number that is attached to this expression in the body of the paper is given at the top of each table. When the expression includes the first power of $\epsilon$ the other terms in the series are negligible, so far as the numbers given in the table are concerned, except for those values of $\phi$ for which the coefficient of the first power of $\epsilon$ vanishes. For these special values, $\eta$ varies as the square of $\epsilon$, and consequently a larger value of $\epsilon$ has been chosen than for the remainder of the table.

The larger numbers are believed to be correct to within two units in the last place. The errors represented by the first two tables can be eliminated by combining observations obtained at azimuths differing by 180°; the other errors can not be so eliminated. For a full discussion of these errors, reference must be made to the body of the paper. Unless otherwise indicated, the sign given at the top of a column applies to all the numbers under it.

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TABLE I. *Inclination axis not perpendicular to the azimuth axis; observations taken at a single azimuth.*

$\epsilon$ is the angular depression of the east end of the inclination axis.

$$\eta = \epsilon \cos^2 I \sin \phi - 0.25\, \epsilon^2 \sin 2I\, (1 + 2 \sin \phi) + \ldots \quad (21)$$

| $I$ | $\epsilon = 30'$ | $\epsilon = 1'$ | | | | | | $I$ |
|---|---|---|---|---|---|---|---|---|
| | $\phi$ = Magnetic Azimuth | | | | | | | |
| | 0° | 5° | 20° | 40° | 60° | 80° | 90° | |
| ° | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ° |
| 0 | —0.00 | +0.09 | +0.34 | +0.64 | +0.87 | +0.98 | +1.00 | 0 |
| 20 | 0.04 | 0.08 | 0.30 | 0.57 | 0.77 | 0.87 | 0.88 | 20 |
| 40 | 0.06 | 0.05 | 0.20 | 0.38 | 0.51 | 0.58 | 0.59 | 40 |
| 60 | 0.05 | 0.02 | 0.08 | 0.16 | 0.22 | 0.25 | 0.25 | 60 |
| 80 | 0.02 | 0.00 | 0.01 | 0.02 | 0.03 | 0.03 | 0.03 | 80 |
| 90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 90 |

TABLE II. *Inclination axis not perpendicular to the azimuth axis; observations taken at two azimuths differing by 90°.*

$\epsilon$ has the same meaning as in Table I.

$$\eta = \sqrt{0.5}\, \epsilon \cos^2 I \sin 2\phi \sin (0.25\, \pi - \phi)$$
$$- \frac{\epsilon^2}{8} \sin 2I \left[ 2 + \cot^2 I \sin^2 \phi \left\{ 3 - 0.5\, (1 + 2 \cos^2 I)\, (1 - \sin 2\phi) \right\} \right] + \ldots \quad (22)$$

unless $I = 0$. If $I = 0$, $\eta = 0.5\, \epsilon \sin 2\phi\, (1 - 0.5 \sin^2 2\phi)^{-\frac{1}{2}}$ (23)

| $I$ | $\epsilon = 30'$ | $\epsilon = 1'$ | | | | | $\epsilon = 30'$ | $I$ |
|---|---|---|---|---|---|---|---|---|
| | $\phi$ = Magnetic Azimuth | | | | | | | |
| | 0° | 5° | 20° | 40° | 60° | 80° | 90° | |
| ° | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ° |
| 0 | —0.00 | +0.09 | +0.36 | +0.68 | +0.55 | +0.18 | —0.00 | 0 |
| 20 | —0.04 | +0.07 | +0.17 | +0.05 | —0.14 | —0.12 | —0.30 | 20 |
| 40 | —0.06 | +0.05 | +0.12 | +0.04 | —0.09 | —0.08 | —0.13 | 40 |
| 60 | —0.05 | +0.02 | +0.05 | +0.02 | —0.04 | —0.03 | —0.08 | 60 |
| 80 | —0.02 | +0.00 | +0.01 | +0.00 | —0.00 | —0.00 | —0.03 | 80 |
| 90 | —0.00 | +0.00 | +0.00 | +0.00 | —0.00 | —0.00 | —0.00 | 90 |

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TABLE III. *The lower end of the azimuth axis inclined towards the magnetic west by an angle $\epsilon$; observations taken at a single azimuth.*

$$\eta = -\epsilon \sin^2 I \tan \phi + 0.25\, \epsilon^2 \sin 2I\, (2 \sin^2 I \tan^2 \phi - 1) + \ldots \quad (25)$$

| $I$ | $\epsilon = 30'$ | $\epsilon' = 1$ | | | | | $I$ |
|---|---|---|---|---|---|---|---|
| | $\phi$ = Magnetic Azimuth | | | | | | |
| | 0° | 5° | 20° | 40° | 60° | 80° | 85° | |
| ° | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ° |
| 0 | —0.00 | —0.00 | —0.00 | —0.00 | —0.00 | —0.00 | —0.00 | 0 |
| 20 | 0.005 | 0.01 | 0.04 | 0.11 | 0.20 | 0.66 | 1.34 | 20 |
| 40 | 0.007 | 0.04 | 0.15 | 0.35 | 0.71 | 2.34 | 4.72 | 40 |
| 60 | 0.006 | 0.07 | 0.27 | 0.63 | 1.30 | 4.25 | 8.57 | 60 |
| 80 | 0.002 | 0.09 | 0.35 | 0.81 | 1.68 | 5.50 | 11.1 | 80 |
| 90 | 0.000 | 0.09 | 0.36 | 0.84 | 1.73 | 5.67 | 11.4 | 90 |

TABLE IV. *The lower end of the azimuth axis inclined towards the magnetic west by an angle $\epsilon$; observations taken in two azimuths differing by 90°.*

$$\eta = -0.5\, \epsilon^2 \tan I \quad (26)$$

| $\epsilon$ | Magnetic Inclination, $I$ | | | | | | $\epsilon$ |
|---|---|---|---|---|---|---|---|
| | 20° | 40° | 60° | 80° | 85° | 88° | |
| ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| 1 | ..... | ..... | ..... | ..... | ..... | —0.00 | 1 |
| 6 | —0.00 | —0.00 | —0.01 | —0.03 | —0.06 | —0.15 | 6 |
| 12 | —0.01 | —0.02 | —0.04 | —0.12 | —0.24 | —0.60 | 12 |
| 30 | —0.05 | —0.11 | —0.23 | —0.74 | —1.5 | —3.8 | 30 |

TABLE V. *Assumed azimuth is numerically too great by an angle $\epsilon$; observations taken at a single azimuth.*

$$\eta = -0.5 \sin 2I\, [\epsilon \tan \phi + 0.5\, \epsilon^2 (1 + 2 \sin^2 I \tan^2 \phi) + \ldots] \quad (28)$$

| $I$ | $\epsilon = 30'$ | $\epsilon = 6'$ | | | | | | | $I$ |
|---|---|---|---|---|---|---|---|---|---|
| | $\phi$ = Magnetic Azimuth | | | | | | | | |
| | 0° | 10° | 20° | 30° | 40° | 50° | 60° | 70° | 80° | |
| ° | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ° |
| 0 | —0.00 | —0.00 | —0.00 | —0.00 | —0.00 | —0.00 | —0.00 | —0.00 | —0.0 | 90 |
| 5 | 0.01 | 0.09 | 0.19 | 0.30 | 0.44 | 0.62 | 0.90 | 1.43 | 3.0 | 85 |
| 10 | 0.02 | 0.18 | 0.37 | 0.59 | 0.86 | 1.22 | 1.77 | 2.81 | 5.8 | 80 |
| 20 | 0.04 | 0.34 | 0.70 | 1.11 | 1.62 | 2.29 | 3.35 | 5.30 | 10.9 | 70 |
| 30 | 0.06 | 0.46 | 0.94 | 1.50 | 2.18 | 3.09 | 4.50 | 7.14 | 14.8 | 60 |
| 40 | 0.06 | 0.52 | 1.08 | 1.71 | 2.48 | 3.52 | 5.12 | 8.11 | 16.8 | 50 |
| 45 | 0.06 | 0.53 | 1.10 | 1.73 | 2.52 | 3.56 | 5.20 | 8.25 | 17.1 | 45 |

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TABLE VI. *Assumed azimuthal difference is numerically too great by an angle $\epsilon$; observations taken at two azimuths nominally differing by 90°.*

$$\eta = 0.25 \sin 2I \sin 2\phi \, [\epsilon + 0.25\,\epsilon^2 (1 + 2\cos^2 I - 4 \cot 2\phi) + \ldots] \quad (29)$$

| $I$ | $\epsilon$ = 30′ | $\epsilon$ = 6′ | | | | | | $I$ |
|---|---|---|---|---|---|---|---|---|
| | Magnetic Azimuth, $\phi$ | | | | | | | |
| | 0° | 5° | 10° | 20° | 30° | 40° | 45° | |
| ° | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ° |
| 0 | −0.00 | +0.00 | +0.00 | +0.00 | +0.00 | +0.00 | +0.00 | 90 |
| 5 | 0.01 | 0.04 | 0.09 | 0.17 | 0.23 | 0.26 | 0.26 | 85 |
| 10 | 0.02 | 0.09 | 0.17 | 0.33 | 0.44 | 0.51 | 0.51 | 80 |
| 20 | 0.04 | 0.17 | 0.33 | 0.62 | 0.84 | 0.95 | 0.97 | 70 |
| 30 | 0.06 | 0.23 | 0.44 | 0.84 | 1.13 | 1.28 | 1.30 | 60 |
| 40 | 0.06 | 0.26 | 0.51 | 0.96 | 1.28 | 1.46 | 1.48 | 50 |
| 45 | 0.06 | 0.26 | 0.51 | 0.97 | 1.30 | 1.48 | 1.50 | 45 |

TABLE VII. *Assumed observed inclination is algebraically too great by the angle $\epsilon$.*

$$\eta = \epsilon \, (\cos^2 I \cos\phi + \sin^2 I \sec\phi) + 0.5\,\epsilon^2 \sin 2I \cos^2 I \tan^2\phi \, (\cos^2\phi + \tan^2 I) + \ldots \quad (31)$$

| $I$ | $\epsilon = 1'$ | | | | | | | | | | $I$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Magnetic Azimuth, $\phi$ | | | | | | | | | | |
| | 0° | 10° | 20° | 30° | 40° | 50° | 60° | 70° | 80° | 85° | |
| ° | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ° |
| 0 | 1.00 | 0.98 | 0.94 | 0.87 | 0.77 | 0.64 | 0.50 | 0.34 | 0.17 | 0.09 | 0 |
| 10 | 1.00 | 0.99 | 0.94 | 0.87 | 0.78 | 0.67 | 0.54 | 0.42 | 0.34 | 0.42 | 10 |
| 20 | 1.00 | 0.99 | 0.95 | 0.89 | 0.83 | 0.75 | 0.67 | 0.64 | 0.82 | 1.42 | 20 |
| 30 | 1.00 | 1.00 | 0.97 | 0.94 | 0.90 | 0.87 | 0.88 | 0.99 | 1.57 | 2.94 | 30 |
| 40 | 1.00 | 1.00 | 0.99 | 0.98 | 0.99 | 1.02 | 1.12 | 1.41 | 2.48 | 4.79 | 40 |
| 50 | 1.00 | 1.01 | 1.01 | 1.04 | 1.09 | 1.19 | 1.38 | 1.85 | 3.45 | 6.77 | 50 |
| 60 | 1.00 | 1.01 | 1.03 | 1.08 | 1.17 | 1.33 | 1.62 | 2.28 | 4.36 | 8.62 | 60 |
| 70 | 1.00 | 1.02 | 1.05 | 1.12 | 1.25 | 1.46 | 1.83 | 2.62 | 5.11 | 10.14 | 70 |
| 80 | 1.00 | 1.02 | 1.06 | 1.15 | 1.29 | 1.53 | 1.96 | 2.84 | 5.60 | 11.13 | 80 |
| 90 | 1.00 | 1.02 | 1.06 | 1.15 | 1.31 | 1.56 | 2.00 | 2.92 | 5.76 | 11.47 | 90 |

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TABLE VIII. *Error produced by a periodic oscillation, of elongation* e, *of the instrument about a vertical axis, or about a horizontal east-west axis.*

$$\eta = \pm \frac{1}{8} e^2 \sin 2I \qquad (33, 34)$$

| $I$ | e | | | | | | | | $I$ |
|---|---|---|---|---|---|---|---|---|---|
| | 0°.5 | 1° | 1°.5 | 2° | 2°.5 | 3° | 3°.5 | 4° | |
| ° | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ° |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 90 |
| 10 | 0.01 | 0.04 | 0.10 | 0.18 | 0.28 | 0.40 | 0.55 | 0.72 | 80 |
| 20 | 0.02 | 0.08 | 0.19 | 0.34 | 0.53 | 0.76 | 1.03 | 1.35 | 70 |
| 30 | 0.03 | 0.11 | 0.26 | 0.45 | 0.71 | 1.02 | 1.39 | 1.82 | 60 |
| 40 | 0.03 | 0.13 | 0.29 | 0.52 | 0.81 | 1.16 | 1.58 | 2.07 | 50 |
| 45 | 0.03 | 0.13 | 0.29 | 0.52 | 0.82 | 1.18 | 1.60 | 2.10 | 45 |

CARNEGIE INSTITUTION OF WASHINGTON,
DEPARTMENT OF TERRESTRIAL MAGNETISM.
*Washington, D. C., Aug. 27, 1912.*

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# DESCRIPTION OF THE C. I. W. MARINE EARTH INDUCTOR.

By J. A. Fleming.

One of the problems[1] encountered in ocean magnetic work covering an extensive area has been that of the satisfactory determination of the variations in the reductions of dip observations to standard with change in magnetic latitude. The problem has been the more difficult because of the mechanical impossibility, despite the most skillful and careful workmanship, of producing a perfect axle. Up to the present time the corrections on standard have been obtained with the aid of the observations at the ports visited where intercomparisons were secured between a standardized earth inductor and the dip circles employed at sea. As these stations are often widely separated and as the conditions aboard ship, where the instruments and needles are in constant motion, are so very different from those on shore, it became desirable that some form of instrument should be devised for the purpose of securing standardizations and the required control on board ship, *i. e.*, in transit from port to port. The satisfactory performance of the earth inductors of various makes and designs, as evidenced by the extensive intercomparison work of the Department,[2] indicated that this type of instrument, if it could be made applicable for observation on board, might be so utilized. After an extended theoretical study[3] of all the conditions involved, the design and construction of such an apparatus was undertaken in the instrument shop of the Department of Terrestrial Magnetism.

The elements of such an apparatus are essentially: (*a*) an improved form of gimbal stand that will maintain an average mean position of equilibrium and which permits complete reversal of the gimbal rings and bearings in order to eliminate errors of level; (*b*) a portable form of earth inductor with such means for rotating the coil as will not in any way, when in use, disturb the gimbal rings, and (*c*) a galvanometer of sufficient sensibility suitable for use at sea.

[1] *Cf.* Bauer, L. A. Some of the problems of ocean magnetic work. *Terr. Mag.*, v. XIV, (164–166).

[2] *Cf.* Fleming, J. A. Comparisons of magnetic observatory standards by the Carnegie Institution of Washington. *Terr. Mag.*, v. XVI (61–84), (137–162).

[3] *Cf.* Dorsey, N. E. The theory of the earth inductor as an inclinometer. *Terr. Mag.*, v. XVIII (1–38).



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Heretofore the *gimbal stand* used has been of the type manufactured by Dover, of England. It consists of a suitable deck support with a U-shaped arm at the top carrying a heavy supporting ring. Two brass knife edges, mounted diametrically opposite in this ring, support a second ring, which in turn carries at the ends of the diameter at right angles to and in the same horizontal plane as that used in the first ring, two brass knife edges supporting an inner ring, on which are provided suitable grooves for footscrews. The two inner free rings must, of course, be carefully balanced, and the inner one properly loaded by a weight to insure a condition of stable equilibrium. It has been found in practice, most probably because of the necessarily soft non-magnetic composition used for the rather blunt knife edges and the consequent wear, that the mean position of rest would frequently be considerably out of level and could not be relied upon to assume always in the mean the same position.

Accordingly in the new gimbal stand as designed by the Department, the soft metal of the knife-edge supports was replaced by strips of hard alloy of platinum and iridium, while the bearing pieces, mounted suitably in the gimbal rings, are of slightly curved agate. (See Plate I, Fig. 1, showing only part of the supporting frame, which has a wide flange at the bottom to facilitate bolting it in place on the deck.) The slight curvature of the agates insures, with a proper balancing weight, that the bearings will be always, except for violent displacements due to motion of vessel in heavy seas, along the same lines of the agates. The outer or bearing ring is attached rigidly to the stand, and is L-shaped with a groove at the lower edge to carry bell-metal balls providing a ball bearing for the load, and with another groove at the top for a second ball bearing to take care of any side thrust. A second ring rotates in these bearings, being centered as carefully as possible and provided with a graduation on its upper surface at intervals of one degree, while two verniers fixed to the outer bearing ring permit settings to be read directly to one-tenth of a degree. The moving ring may be clamped for any reading of the circle; it carries two supporting knife edges of the platinum-iridium alloy, on which is mounted the larger, and outer, free ring of the gimbal proper. As shown in the figure, suitable lugs carry the agate supports, at right angles to which the moving ring carries similar knife edges. The latter are in the same plane as the other knife edges, and in turn support similarly the inner gimbal ring on which the instru-

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ment may be mounted. The material improvement, in addition to that of the supports and bearings, is in the reversible feature for the two gimbal rings. A lead weight is mounted by four supporting rods from the inner ring; this weight may be adjusted vertically by means of a screw-arm and lock nuts. Sliding clamps have been provided on the inner ring, so that the three grooved footscrews of the earth inductor or other instrument used may be clamped in the V's; the clamping heads and nuts are on the lower side of the ring and can not be seen in the figure. When the stand is not in use, the gimbal rings are lifted off the agates and are supported by wooden blocks and clamps.

The *earth inductor* constructed for this apparatus is shown in Figs. 2 and 3, Plate I. The double center base is of the usual pattern used for theodolites, with three leveling footscrews and slow tangent motions for each center. The horizontal circle graduation is 12 cm. in diameter, the least graduation being 30 minutes of arc and may be read, by means of two verniers, directly to one minute of arc; the very sharp, clean graduations permit estimations to one-quarter of a minute. The lower center of the base is not necessary, but for this inductor the double center base was used simply because it was in stock, and thus made possible the early completion of the instrument. The standards carrying the ring in which the coil is mounted and on which the rotating gear and the vertical circle verniers are also mounted, is attached permanently to the base. The ring carrying the bearings for the rotation axis of the coil is 78 mm. inside diameter; in it, at right angles to the axle supports in the standards, are provided centering and bearing agates, and to it are attached the vertical circle and the commutator brushes with suitable wire connections to two binding posts through the horizontal axle on the vertical circle side of the instrument. To make possible the more accurate adjustment of the brushes, it was originally contemplated to make them adjustable around the axis of the commutator, but this was not done because of the mechanical complications that would have been introduced. Care was used, however, to set the brushes very closely to eliminate the necessity, for practical purposes, of this adjustment. The vertical circle is 10.2 cm. in diameter, with a least graduation of 30 minutes of arc, and may be read directly, by two fixed verniers, to one minute and, by estimation, to one-quarter of a minute. Suitable means for clamping vertical circle and for slow motion are provided.



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The bearings of the rotation axis of the coil are of brass, being V-shaped in longitudinal section and running in agate cups burnished in the brass centering supports in the supporting ring. The coil is held in place by two U-shaped pieces of brass which carry the bearing ends of the rotation axis. At one end of the rotation axis is mounted the commutator and, at the other end, a miter gear for use in the rotation of the coil. The spool of the coil is made of hard rubber[4] of 24 mm. outside thickness, and of 74 mm. outside diameter. The inside diameter of the winding of the coil is 26 mm., the outside diameter, 73 mm., and the width of winding, 17.5 mm. There are 65 layers (3.162 turns) of double wound silk magnet wire No. 30 B. & S. gauge with a double thickness of paper at every fifth layer. For protection against moisture conditions encountered on board ship and against possible abrasion and short-circuiting of the turns, the outer surface of the coil and its connections are heavily coated with paraffin. The resistance of the coil is about 175 ohms.

The instrument has been very carefully balanced by the use of counterweights attached, as has been found necessary, to those parts which may take up different positions at different times of observation; *e. g.*, the coil in its mounting has been carefully balanced around the axis supporting the bearing ring, and the whole has been balanced about the center line of the spindle bearing. Thus when the instrument is mounted, the gimbal ring is supposed to remain level for any orientation or position of any part of the instrument.

For the purpose of determining the magnetic meridian, a sighting telescope and a compass are provided, suitable mounting wyes being placed so that the line of sight or the magnetic axis of the needle will be in the vertical plane through the rotation axis of the coil. The magnetic meridian may thus be determined by sighting upon marks of known magnetic bearing or by actual observation of the compass. Parallax in the compass readings is avoided with the aid of mirrors mounted immediately below the ends of the needle.

The gearing for rotating the coil of the earth inductor is self-contained, and is shown clearly in Figs. 2 and 3, Plate I. A hole has been drilled through the center of the spindle and a shaft mounted in it with a miter gear at the upper end in suitable bear-

[4] This material was used instead of brass because of the greater mechanical ease of maintaining insulation and eliminating induction effects.

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ing; this engages a second miter gear mounted on a shaft set at about 45° from the vertical in fixed bearings on the standard frame. A third gear at the upper end of the inclined shaft engages a similar miter gear attached to an axle rotating in the center of the horizontal bearing end of the supporting ring. Inside of the supporting ring, there is attached to this axle a gear of 102 teeth mounted in a hollow spherical frame which permits the coil to turn freely inside it, and engages a gear of 25 teeth attached to the rotation axis of the coil.

The method of transmission of the rotary motion without disturbing the gimbal rings is as follows: At the point of intersection of the two diameters through the supporting knife edges of the two gimbal rings a very small universal joint has been mounted; this is made so as to be adjustable vertically, and has sufficient lost motion between its two parts to allow for the very slight play between the two rings in their bearings. The motion is transmitted to this universal joint by means of two gears, shafts, and a handle (see Plate I, Fig. 1) carried in a frame attached rigidly in a diameter of the reversible bearing ring of the gimbal. By means of a slight inclination of the support carrying the transmitting shaft, it is possible to rotate the operating crank in any position of the ring without interference from the supporting frame. A cross pin in the lower end of the rod through the spindle bearing of the base of the earth inductor engages in a slot in the upper part of the universal joint, just visible in figure 1. At the intersection of the two diameters containing the supporting knife edges there is no motion relative to the instrument; there results, thus, no effect upon the position of the gimbal rings when the coil is spun. Theoretically, of course, the universal joint should be a point, and accordingly, it has been made as small as is possible for practical use; the tests show that, with the gimbal weight mounted as on board ship, no effect is produced on the average position of the gimbal rings. The gears used are all of the same size except the hollow frame one in which the coil rotates; the multiplication of rotation is in the ratio of 102 to 25, or approximately four to one. The wires from the earth-inductor binding posts to the leads to the galvanometer are very fine and are made with long spirals to eliminate any effect on the position of the gimbal ring.

For the purpose of rotating the coil at land stations, a special tripod clamp has been provided with a bearing for turning the crank which is connected with the center shaft in the spindle

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bearing by means of brass shafts and two universal joints. The weight of the present earth inductor is about 5 kilograms, while that of the Wild-Eschenhagen pattern is about two and a half times as much. The comparisons of it with the standard earth inductor of the latter pattern have been extremely satisfactory, the resulting difference being on the order of about 0.3 minute.

The *galvanometer* used is of the moving coil type, manufactured by the Leeds & Northrup Company, of Philadelphia, with some slight modifications specified by the Department. The moving coil is suspended between straight upper and lower suspensions of 0.002-inch phosphor bronze ribbon. These suspensions have proved to be amply strong for carrying the instrument about and for the more or less rough motions encountered during heavy seas on board ship. The coil may be clamped in position when not in use by means of a sliding clamp at the back of the tube and the tension of the suspension fibers adjusted by a sliding rod and set screw at the lower end of the tube. The tube containing the coil and suspensions may be quickly removed by loosening two clamping nuts and readily replaced by a reserve tube, if necessary. A glass window allows easy inspection of the system. The reflecting mirror has a plane surface. The galvanometer resistance is 317 ohms and the critical damping resistance about 125 ohms. The deflections are as nearly as possible proportional to current and the sensibility practically the same for minus deflections as for positive ones. The sensibility specified was one mm. at scale distance 1 meter $= 10^{-8}$ ampere. The period is about 2.4 seconds. To prevent corrosion and warping, owing to the hygrometric conditions at sea, the magnet and core are protected by paint and the base is made of hard rubber. The stray magnetic field was specified to be as small as possible.

The coil may be balanced by means of balancing nuts mounted at its lower end so as to make the zero reading practically independent of changes in level of the instrument up to 20°. Owing primarily to defective centering of balancing rods and nuts, it has proved somewhat difficult to balance the coil of the galvanometer first supplied with the apparatus, and the system is liable to become unbalanced in a short time. A new galvanometer in which these mechanical defects have been eliminated has accordingly been supplied to the *Carnegie* for use, beginning at Port Stanley, Falkland Islands, in February, 1913.

The null *method of observation*, that is to say, the determina-

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tion of the position of the rotation axis of the inductor coil for no current indication in the galvanometer, commonly in use on land, can not, of course, be used on board ship. It is, therefore, necessary to observe deflections for particular settings of the rotation axis of the coil on either side of the line of magnetic inclination, taking care that a constant speed of rotation is maintained. With the aid of a metronome or chronometer beats, experiment has shown that there is comparatively little trouble in holding the speed sufficiently constant for practical purposes, account being taken of the desired accuracy of deflection determination for the comparatively small displacements from the line of actual magnetic inclination. By observing the mean deflections of the galvanometer for righthand and lefthand rotation of the coil, respectively, when the rotation axis is in the magnetic meridian, it is possible to determine at once the position of balance, or the vertical circle reading of the true line of inclination, by linear interpolation from the vertical circle settings used. There being no means provided to determine directly the reading of the vertical circle when the rotation axis is vertical, corresponding observations and interpolations must be made with the vertical circle turned in azimuth 180° from its first position. The graduation is continuous through 360°, so that the difference between the two positions for balance so determined gives twice the complement of the angle of magnetic inclination, from which the value may be at once deduced.

Credit is due Mr. J. A. Widmer, chief instrument maker of the Department, and his assistants, for the excellent execution of the mechanical detail.

CARNEGIE INSTITUTION OF WASHINGTON,
DEPARTMENT OF TERRESTRIAL MAGNETISM,
*Washington, D. C., Sept. 1912.*

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# REPORT ON THE C. I. W. MARINE EARTH INDUCTOR.

By C. W. Hewlett.

The apparatus was installed on board the *Carnegie* at Papeete, Tahiti, in October, 1912, as follows: The inductor was mounted on the new gimbal stand (Plate I, Fig. 1) in the after observatory, $C$[1]; the galvanometer, in order to eliminate any possible magnetic effect, was fastened by a bolt passing through the hard rubber base of the instrument to a substantial shelf against a wood wall about thirty feet aft of the inductor; communication between the observers at the earth inductor and the galvanometer was established by means of a simple signaling device. The writer, after having taken part in the experimental work at Washington, was assigned as observer on board the *Carnegie* and was placed in charge of the earth-inductor work by Mr. Peters, in command of the vessel, who afforded him every possible facility.

The chief difficulty at sea has been the maintenance of the adjustment of the galvanometer, owing to some minor imperfections which can easily be remedied.[2] It has been found possible to adjust readily the system at shore stations so that a tip of 20° in any direction, with a scale distance of 58 cm., causes a change of not more than 1 mm. in the galvanometer zero. The failure to maintain balance at sea is also partly due to the temperature and humidity changes. Fortunately, after some practice, it has been found possible to make the adjustment for balance on board, even when the sea is moderately rough, within three to fifteen minutes, depending upon how badly the coil was out of balance and upon the character of the ship's motion. In moderately rough seas, the wandering of the zero is reduced to a range of 5 to 10 mm. when the galvanometer is used with a 100-ohm shunt. Owing to the lack of symmetry in the balancing arrangements, it is difficult to throw the center of gravity of the coil into the line of suspension. By manipulation, it has been found easier to place the center of gravity in a plane at right angles to the coil than in the plane of the coil; for this reason the galvanometer has been mounted with the plane of its coil fore and aft.

The *general scheme of observation* used on board the *Carnegie* between Papeete, Tahiti, and Coronel, Chile, during October 15 to November 26, 1912, was as follows: The galvanometer was

[1] *Terr. Mag.*, v. XV, 1910, plate III, station *C*, opposite p. 62.

[2] *Terr. Mag.*, v. XVIII, 1913, p. 44.



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shunted so that its turning points could be read satisfactorily. The horizontal circle of the inductor was set with the rotation axis in the magnetic meridian. The vertical circle was then set approximately one degree less than the actual magnetic inclination and the coil was spun, in a righthand direction, at the fixed speed adopted for the particular observations, and the turning points of the galvanometer were noted. The coil was next spun in the opposite direction at the same speed and similar galvanometer readings were made. Similar readings followed for the vertical circle set about one degree above the approximate reading of the magnetic inclination. From these readings the sensibility of the instrument was determined as also, by linear interpolation, the setting for which the mid-point will be independent of the direction of spin. Thus, if $A$ was the first vertical circle setting, the reading of the vertical circle for the position of balance, assuming no appreciable variation in thermoelectromotive force due to possible changes in temperature at the commutator, would be $A + \left(\frac{D_1}{D_1 - D_2}\right)\Delta$, where $D_1$ is the difference between the galvanometer readings for righthand and lefthand rotation at the first vertical circle setting, $D_2$ the corresponding quantity for the second setting of the vertical circle, and $\Delta$ the difference between the two settings of the vertical circle. Usually the observation began with the vertical circle east of the magnetic meridian, so that a second determination similar to the one outlined above was then made with the vertical circle west. From these two interpolated positions of balance the angle of dip may be determined readily by combination of the results. The speeds used in rotating the coil have been within the limits of 60 to 120 turns of the crank per minute; by reason of the multiplication of the gear system, this is equivalent to from 250 to 500 revolutions per minute of the coil.

As the interpolation term may be subject to error because of any change in the sensibility of the galvanometer, or in the quality of insulation, or in the resistance of the various contacts and portions of the circuit, a sharp lookout was kept for any leakage, this being indicated by a decrease in the sensibility of the galvanometer. To prevent this, all insulated surfaces were greased with vaseline or good kerosene and wiped off and regreased frequently. The term may also be subject to error if there is variation in the thermoelectromotive force, due to changes of the temperature at the commutator during the observation. The commutator was, there-

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fore, kept well lubricated with vaseline, in order to reduce the possibility of such variation.

For the above scheme of observation four persons have been generally used: two at the galvanometer, one to read and the other to record; two at the earth inductor, one to make the circle settings and to rotate the coil, the other to record the settings and to keep the meridional plane of the instrument in the magnetic meridional plane. The last operation is of the same importance as in the use of the dip circle, and is maintained by reference to a standard Ritchie compass, where simultaneous observations are being made by another observer in connection with the horizontal intensity observations.

In the first work on board ship it was attempted to form mental means of the galvanometer deflections. This was found to be fairly satisfactory when the sea was smooth, but impracticable under ordinary conditions, on account of the swinging of the gimbal. The method finally adopted was to read ten pairs of turning points for each operation of the earth inductor. It has been found that four determinations of the dip, namely, circle east and circle west, with the gimbal rings both direct and reversed, are necessary in order to give a result that can be repeated within one or two minutes of arc (this statement applying for dips from 45° to 55° and total intensity from 0.4 to 0.5 C. G. S.). The whole operation as outlined requires from 13 to 16 minutes.

At times the successive determinations have agreed exactly, more frequently they have differed by a few hundredths of a degree, and occasionally they have varied by three or four tenths of a degree. The cause or causes of the occasional large variations are being investigated. The earth-inductor observations have been made on nearly every day the dip circle was used, sometimes before and after, and sometimes in the middle of the dip-circle work, so that the earth-inductor values and those of the dip circle apply to the same times and positions. On two different occasions the whole afternoon was given to determination of dip by the earth inductor. Of six determinations, all applying to the same position and time on one of these days, the extreme difference from the mean in the case of one value was 0°.25, of a second value 0.°18, while the other values differed by less than 0.°1 from the mean. The second day's work gave eight determinations, none of which differed from the mean by as much as 0.°1. This work was done while the ship was becalmed so that the only motion was rolling. It is hoped that the mean values of the magnetic inclination determined at sea with the inductor may be depended upon finally within an absolute accuracy of three minutes of arc, or less.

*On the "Carnegie," Coronel, Chile, Nov. 26, '12.*

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# *LETTERS TO THE EDITOR*

## READINGS OF THE MAGNETIC DECLINATION AND OF THE TEMPERATURE AT PORT BURWELL, CANADA, ON THE DAY OF THE SOLAR ECLIPSE, OCTOBER 10, 1912.

I have pleasure in transmitting herewith the tabulated results of magnetic declination and of temperature observations made at Port Burwell on October 10, 1912.[1] The geographic position of Port Burwell is: latitude, 60° 24′.8 N.; longitude, 64° 41′.9 West of Greenwich.

These observations were made in response to a circular letter received from the Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington with respect to proposed magnetic and allied observations during the total solar eclipse of October 10, 1912. Elliott Magnetometer No. 146 was used by the observers, Messrs. W. E. W. Jackson and W. B. Wiegand, and the results were reduced to the Toronto standard.

The weather conditions were: fresh west to northwest gale, with heavy snow showers.

R. F. STUPART.

*Meteorological Service,*
*Toronto, Ontario, December 13, 1912.*

*Temperature Observations at Port Burwell, October 10, 1912.*

(In degrees Fahrenheit.)

| G.M.T. | Dry Bulb | Wet Bulb | G.M.T. | Dry Bulb | Wet Bulb | G.M.T. | Dry Bulb | Wet Bulb | G.M.T. | Dry Bulb | Wet Bulb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| h m | ° | ° | h m | ° | ° | h m | ° | ° | h m | ° | ° |
| 10 59 | 25.5 | 25.6 | 12 19 | 27.3 | 26.6 | 13 39 | 25.0 | 25.0 | 14 59 | 25.6 | 24.6 |
| 11 4 | 25.7 | 25.9 | 24 | 26.5 | 26.7 | 44 | 25.1 | 25.1 | 15 4 | 25.4 | 24.3 |
| 9 | 26.2 | 26.0 | 29 | 26.0 | 26.1 | 49 | 25.0 | 25.0 | 9 | 25.3 | 24.2 |
| 14 | 26.6 | 26.2 | 34 | 25.3 | 25.6 | 54 | 24.7 | 24.6 | 14 | 25.5 | 24 5 |
| 19 | 26.2 | 26.1 | 39 | 25.0 | 25.1 | 59 | 24.7 | 24.6 | 19 | 25.3 | 24.3 |
| 24 | 26.3 | 26.1 | 44 | 24.7 | 24.8 | 14 4 | 24.7 | 24.3 | 24 | 25.4 | 24.7 |
| 29 | 26.3 | 26.0 | 49 | 24.3 | 24.5 | 9 | 24.8 | 24.5 | 29 | 25.6 | 25.0 |
| 34 | 26.3 | 26.0 | 54 | 24.4 | 24 6 | 14 | 24.8 | 24.3 | 34 | 25.5 | 25.0 |
| 39 | 26.3 | 26.0 | 59 | 24.1 | 24.2 | 19 | 25.2 | 24.6 | 39 | 25.5 | 25.0 |
| 44 | 26.7 | 26.2 | 13 4 | 24.1 | 24.2 | 24 | 25.3 | 24.8 | 44 | 25.2 | 24.8 |
| 49 | 27.2 | 26.9 | 9 | 24.8 | 24.8 | 29 | 25.1 | 24.4 | 49 | 25.6 | 25.5 |
| 54 | 27.6 | 27.1 | 14 | 24.8 | 24.8 | 34 | 25.3 | 24.7 | 54 | 25.6 | 25.6 |
| 59 | 27.2 | 26.8 | 19 | 24.9 | 25.0 | 39 | 25.6 | 24.9 | 59 | 25.2 | 25.0 |
| 12 4 | 27.0 | 26.5 | 24 | 25.0 | 25.0 | 44 | 25.6 | 24.9 | 16 4 | 25.0 | 24.5 |
| 9 | 27.0 | 26.3 | 29 | 24.5 | 24.4 | 49 | 25.2 | 24.3 | 9 | 25.2 | 23.6 |
| 14 | 27.0 | 26.0 | 34 | 25.0 | 24.8 | 54 | 25.5 | 24.5 | | | |

[1] Copies of the Agincourt magnetic curves for the same date were also transmitted.—ED.



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| G. M. T. | Decl'n W 43° + | G. M. T. | Decl'n W 43° + | G. M. T. | Decl'n W 43° + | G. M. T. | Decl'n W 43° + | G. M. T. | Decl'n W 43° + | G. M. T. | Decl'n W 43° + |
|---|---|---|---|---|---|---|---|---|---|---|---|
| h m | ′ | h m | ′ | h m | ′ | h m | ′ | h m | ′ | h m | ′ |
| 10 45 | 32.4 | 11 43 | 30.8 | 12 41 | 36.9 | 13 38 | 43.1 | 14 35 | 48.6 | 15 32 | 50.3 |
| 46 | 31.4 | 44 | 31.8 | 42 | 36.6 | 39 | 43.6 | 36 | 48.6 | 33 | 49.1 |
| 47 | 30.8 | 45 | 32.8 | 43 | 36.6 | 40 | 43.8 | 37 | 48.6 | 34 | 48.4 |
| 48 | 31.4 | 46 | 33.3 | 44 | 37.4 | 41 | 43.1 | 38 | 48.6 | 35 | 47.4 |
| 49 | 32.4 | 47 | 31.8 | 45 | 38.4 | 42 | 43.1 | 39 | 48.6 | 36 | 47.1 |
| 50 | 32.1 | 48 | 31.8 | 46 | 38.4 | 43 | 42.4 | 40 | 47.9 | 37 | 47.1 |
| 51 | 31.6 | 49 | 31.4 | 47 | 37.9 | 44 | 41.3 | 41 | 48.1 | 38 | 47.1 |
| 52 | 30.1 | 50 | 32.1 | 48 | 35.9 | 45 | 41.8 | 42 | 47.4 | 39 | 46.8 |
| 53 | 30.1 | 51 | 32.1 | 49 | 36.9 | 46 | 41.8 | 43 | 46.8 | 40 | 46.1 |
| 54 | 30.4 | 52 | 31.4 | 50 | 36.9 | 47 | 42.1 | 44 | 46.9 | 41 | 45.4 |
| 55 | 30.4 | 53 | 30.9 | 51 | 36.4 | 48 | 42.1 | 45 | 47.1 | 42 | 45.4 |
| 56 | 31.1 | 54 | 31.9 | 52 | 36.4 | 49 | 42.1 | 46 | 46.1 | 43 | 44.8 |
| 57 | 32.8 | 55 | 31.9 | 53 | 36.4 | 50 | 42.8 | 47 | 46.1 | 44 | 43.8 |
| 58 | 32.4 | 56 | 30.8 | 54 | 36.4 | 51 | 44.3 | 48 | 46.4 | 45 | 44.4 |
| 59 | 33.1 | 57 | 31.6 | 55 | 36.9 | 52 | 43.9 | 49 | 47.1 | 46 | 44.9 |
| 11 00 | 33.4 | 58 | 31.6 | 56 | 37.4 | 53 | 43.9 | 50 | 46.6 | 47 | 46.1 |
| 01 | 33.6 | 59 | 32.3 | 57 | 37.4 | 54 | 43.9 | 51 | 46.1 | 48 | 46.1 |
| 02 | 34.4 | 12 00 | 32.9 | 58 | 37.4 | 55 | 43.4 | 52 | 46.8 | 49 | 46.1 |
| 03 | 34.1 | 01 | 34.1 | 59 | 37.4 | 56 | 43.4 | 53 | 47.8 | 50 | 46.8 |
| 04 | 32.1 | 02 | 34.4 | 13 00 | 37.4 | 57 | 43.8 | 54 | 46.9 | 51 | 46.8 |
| 05 | 30.4 | 03 | 35.1 | 01 | 36.9 | 58 | 44.4 | 55 | 46.4 | 52 | 46.1 |
| 06 | 31.1 | 04 | 34.8 | 02 | 36.9 | 59 | 44.4 | 56 | 46.1 | 53 | 46.1 |
| 07 | 29.8 | 05 | 34.8 | 03 | 36.9 | 14 00 | 44.1 | 57 | 45.8 | 54 | 46.1 |
| 08 | 28.8 | 06 | 34.3 | 04 | 36.3 | 01 | 44.8 | 58 | 47.1 | 55 | 46.1 |
| 09 | 29.8 | 07 | 34.1 | 05 | 35.8 | 02 | 43.8 | 59 | 47.4 | 56 | 45.8 |
| 10 | 30.4 | 08 | 35.8 | 06 | 36.4 | 03 | 44.6 | 15 00 | 46.1 | 57 | 45.4 |
| 11 | 31.6 | 09 | 34.6 | 07 | 36.4 | 04 | 45.4 | 01 | 44.8 | 58 | 45.6 |
| 12 | 32.6 | 10 | 35.9 | 08 | 37.9 | 05 | 46.1 | 02 | 45.6 | 59 | 46.6 |
| 13 | 33.1 | 11 | 37.3 | 09 | 37.9 | 06 | 46.8 | 03 | 46.9 | 16 00 | 46.6 |
| 14 | 33.4 | 12 | 37.3 | 10 | 38.4 | 07 | 46.8 | 04 | 46.8 | 01 | 46.1 |
| 15 | 33.4 | 13 | 37.1 | 11 | 38.4 | 08 | 46.8 | 05 | 46.8 | 02 | 46.4 |
| 16 | 34.4 | 14 | 37.1 | 12 | 38.4 | 09 | 46.8 | 06 | 46.8 | 03 | 47.8 |
| 17 | 35.3 | 15 | 35.3 | 13 | 38.4 | 10 | 46.8 | 07 | 46.6 | 04 | 47.4 |
| 18 | 36.4 | 16 | 33.6 | 14 | 36.9 | 11 | 46.1 | 08 | 46.6 | 05 | 47.8 |
| 19 | 37.8 | 17 | 30.1 | 15 | 36.9 | 12 | 46.1 | 09 | 47.1 | 06 | 47.8 |
| 20 | 37.6 | 18 | 28.1 | 16 | 38.8 | 13 | 44.8 | 10 | 47.8 | 07 | 48.4 |
| 21 | 33.1 | 19 | 27.3 | 17 | 39.8 | 14 | 44.9 | 11 | 48.4 | 08 | 49.1 |
| 22 | 29.8 | 20 | 27.6 | 18 | 39.1 | 15 | 46.1 | 12 | 47.9 | 09 | 50.8 |
| 23 | 27.1 | 21 | 28.1 | 19 | 38.1 | 16 | 46.1 | 13 | 49.4 | 10 | 52.3 |
| 24 | 23.1 | 22 | 26.8 | 20 | 38.1 | 17 | 46.1 | 14 | 49.4 | 11 | 52.1 |
| 25 | 25.8 | 23 | 26.3 | 21 | 36.8 | 18 | 46.4 | 15 | 47.8 | 12 | 52.9 |
| 26 | 27.6 | 24 | 27.4 | 22 | 37.1 | 19 | 46.4 | 16 | 48.4 | 13 | 51.8 |
| 27 | 29.1 | 25 | 29.4 | 23 | 38.1 | 20 | 46.4 | 17 | 49.8 | 14 | 52.4 |
| 28 | 29.4 | 26 | 30.3 | 24 | 38.1 | 21 | 46.4 | 18 | 49.8 | 15 | 53.4 |
| 29 | 29.8 | 27 | 31.4 | 25 | 37.3 | 22 | 46.4 | 19 | 49.1 | 16 | 54.1 |
| 30 | 29.8 | 28 | 32.8 | 26 | 37.1 | 23 | 47.4 | 20 | 49.1 | 17 | 53.4 |
| 31 | 29.1 | 29 | 34.6 | 27 | 38.6 | 24 | 46.8 | 21 | 49.1 | 18 | 53.6 |
| 32 | 30.8 | 30 | 36.1 | 28 | 38.6 | 25 | 45.6 | 22 | 50.1 | 19 | 54.1 |
| 33 | 30.8 | 31 | 36.1 | 29 | 39.1 | 26 | 45.6 | 23 | 50.1 | 20 | 54.1 |
| 34 | 30.8 | 32 | 37.6 | 30 | 40.1 | 27 | 45.6 | 24 | 51.1 | 21 | 54.1 |
| 35 | 30.8 | 33 | 37.1 | 31 | 41.4 | 28 | 46.4 | 25 | 49.4 | 22 | 54.8 |
| 36 | 29.1 | 34 | 36.3 | 32 | 42.1 | 29 | 46.4 | 26 | 49.4 | 23 | 55.8 |
| 37 | 30.8 | 35 | 35.8 | 33 | 42.3 | 30 | 46.4 | 27 | 49.1 | 24 | 55.8 |
| 38 | 30.8 | 36 | 34.6 | 34 | 41.9 | 31 | 46.9 | 28 | 49.1 | 25 | 54.6 |
| 39 | 31.8 | 37 | 33.1 | 35 | 42.4 | 32 | 47.6 | 29 | 48.8 | 26 | 54.3 |
| 40 | 31.8 | 38 | 35.3 | 36 | 42.1 | 33 | 47.6 | 30 | 48.8 | 27 | 53.8 |
| 41 | 31.8 | 39 | 36.1 | 37 | 42.4 | 34 | 47.6 | 31 | 49.8 | 28 | 53.8 |
| 42 | 30.8 | 40 | 36.9 | | | | | | | | |



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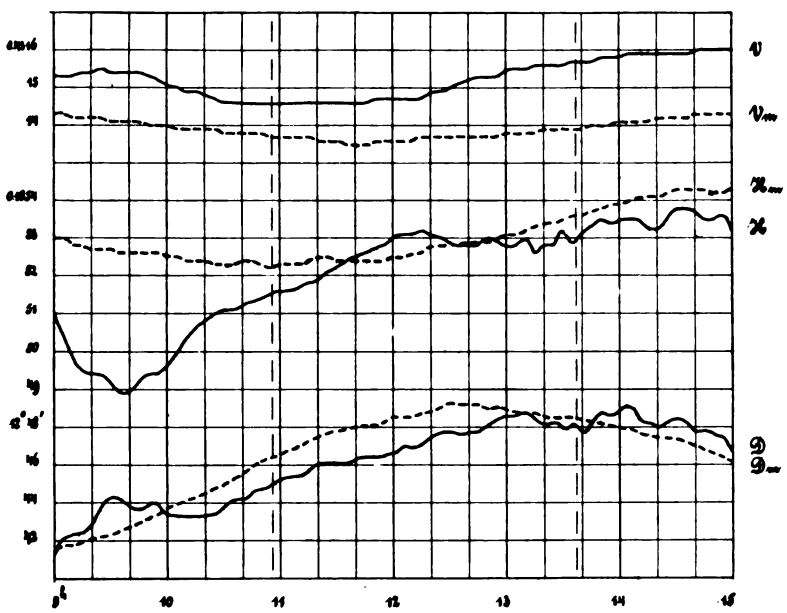
## MAGNETIC OBSERVATIONS ON THE DAY OF THE SOLAR ECLIPSE OF APRIL 17, 1912, AT DE BILT.

With reference to the article by Mr. O. H. Tittmann[1] concerning the solar eclipse of April 28, 1911, it seems to me of interest to give here some communications about the magnetic registrations at De Bilt (Lat. 52° 6′ N., Long. 5° 11′ = $0^h$ $20^m$ $44^s$ E. of Gr.) at the time of the solar eclipse of April 17, 1912.

The magnetic condition of the Earth in April, 1912, may be inferred from the following list, containing the mean magnetic character (scale 0, 1, 2 of Innsbruck) from April 6 to 25, computed from the data of 42 magnetic observatories given in "Caractère magnétique de chaque jour des mois Avril-Juni, 1912":

| April: | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean character: | 1.0 | 0.8 | 0.1 | 0.1 | 1.0 | 0.1 | 0.2 | 0.2 | 0.8 | 1.3 | 1.1 | 1.0 | 0.6 | 0.6 | 0.5 | 0.0 | 0.1 | 0.3 | 0.2 | 0.3 |

This list shows that a rather quiet period was followed by a more or less disturbed period from April 14 to 20; on April 21 a new series of quiet days began. At De Bilt the solar eclipse commenced at $10^h$ $56^m$ Greenwich mean civil time, and ended at $13^h$ $37^m$; the central line passed about 125 km. southeast of De Bilt. Although the Earth's magnetic condition was somewhat disturbed at the time of the eclipse, yet the diagram of the declination (see Figure) evidently shows an effect of the eclipse, the increase of the declination in the forenoon being less than ordinarily.



*Variations of the magnetic elements at De Bilt on April 17, 1912.*

[1] *Terr. Mag.*, v. XVII, 1912, p. 21.

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*Magnetic Observations at De Bilt, Holland, on the day of the Solar Eclipse, April 17, 1912.*

| 1912 G. M. T. | Decl'n W. 12°+ | | Hor. Int. 18400γ+ | | Ver. Int. 43000γ+ | | 1912 G. M. T. | Decl'n W. 12°+ | | Hor. Int. 18400γ+ | | Ver. Int. 43000γ+ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Apr. 17 | Normal | Apr. 17 | Normal | Apr. 17 | Normal | | Apr. 17 | Normal | Apr. 17 | Normal | Apr. 17 | Normal |
| h m | ′ | ′ | γ | γ | γ | γ | h m | ′ | ′ | γ | γ | γ | γ |
| 9 0 | 41.3 | 41.5 | 110 | 130 | 153 | 143 | 12 0 | 46.6 | 48.5 | 130 | 125 | 147 | 136 |
| 5 | 42.1 | 41.8 | 105 | 130 | 153 | 143 | 5 | 47.0 | 48.5 | 131 | 125 | 147 | 136 |
| 10 | 42.2 | 41.8 | 99 | 128 | 153 | 142 | 10 | 46.9 | 48.6 | 131 | 126 | 147 | 136 |
| 15 | 42.2 | 41.9 | 95 | 128 | 154 | 142 | 15 | 47.1 | 48.7 | 132 | 126 | 147 | 137 |
| 20 | 42.9 | 42.1 | 94 | 127 | 154 | 142 | 20 | 47.4 | 48.8 | 131 | 128 | 149 | 137 |
| 25 | 43.6 | 42.2 | 94 | 127 | 155 | 142 | 25 | 47.7 | 49.1 | 130 | 128 | 149 | 137 |
| 30 | 44.3 | 42.3 | 92 | 127 | 154 | 141 | 30 | 47.7 | 49.3 | 129 | 129 | 150 | 137 |
| 35 | 44.2 | 42.5 | 89 | 126 | 154 | 141 | 35 | 47.6 | 49.2 | 128 | 128 | 151 | 137 |
| 40 | 43.8 | 42.7 | 89 | 126 | 154 | 141 | 40 | 47.7 | 49.2 | 128 | 129 | 152 | 137 |
| 45 | 43.6 | 43.0 | 92 | 126 | 154 | 141 | 45 | 47.7 | 49.2 | 128 | 129 | 153 | 137 |
| 50 | 44.0 | 43.2 | 94 | 126 | 153 | 140 | 50 | 48.1 | 49.0 | 130 | 129 | 153 | 137 |
| 55 | 44.0 | 43.4 | 94 | 126 | 152 | 140 | 55 | 48.4 | 49.1 | 129 | 130 | 153 | 137 |
| 10 0 | 43.3 | 43.7 | 96 | 125 | 151 | 140 | 13 0 | 48.6 | 48.9 | 128 | 131 | 155 | 138 |
| 5 | 43.3 | 43.9 | 99 | 125 | 150 | 139 | 5 | 48.6 | 48.8 | 128 | 131 | 155 | 138 |
| 10 | 43.3 | 44.1 | 103 | 124 | 149 | 139 | 10 | 48.8 | 48.7 | 130 | 132 | 155 | 138 |
| 15 | 43.3 | 44.3 | 106 | 124 | 149 | 139 | 15 | 48.4 | 48.7 | 126 | 133 | 156 | 138 |
| 20 | 43.3 | 44.5 | 108 | 124 | 148 | 139 | 20 | 48.1 | 48.6 | 128 | 134 | 156 | 139 |
| 25 | 43.4 | 44.8 | 110 | 123 | 147 | 139 | 25 | 48.3 | 48.5 | 128 | 134 | 156 | 139 |
| 30 | 43.8 | 45.0 | 111 | 123 | 146 | 138 | 30 | 47.9 | 48.5 | 132 | 135 | 156 | 139 |
| 35 | 44.1 | 45.3 | 111 | 123 | 146 | 138 | 35 | 48.2 | 48.5 | 129 | 136 | 157 | 139 |
| 40 | 44.2 | 45.7 | 112 | 124 | 146 | 138 | 40 | 47.7 | 48.4 | 131 | 136 | 157 | 139 |
| 45 | 44.5 | 46.0 | 113 | 124 | 146 | 138 | 45 | 48.2 | 48.3 | 133 | 137 | 157 | 140 |
| 50 | 44.7 | 46.2 | 114 | 123 | 146 | 138 | 50 | 48.7 | 48.2 | 135 | 138 | 158 | 140 |
| 55 | 45.0 | 46.4 | 115 | 122 | 146 | 137 | 55 | 48.6 | 48.1 | 134 | 139 | 158 | 140 |
| 11 0 | 45.2 | 46.6 | 116 | 123 | 146 | 137 | 14 0 | 48.8 | 48.0 | 135 | 139 | 158 | 141 |
| 5 | 45.4 | 46.8 | 116 | 123 | 146 | 137 | 5 | 49.1 | 47.9 | 135 | 140 | 159 | 141 |
| 10 | 45.4 | 47.0 | 117 | 123 | 146 | 137 | 10 | 48.4 | 47.7 | 135 | 141 | 159 | 141 |
| 15 | 45.8 | 47.3 | 118 | 124 | 146 | 137 | 15 | 48.2 | 47.6 | 133 | 141 | 159 | 141 |
| 20 | 46.0 | 47.5 | 119 | 125 | 146 | 136 | 20 | 48.0 | 47.5 | 132 | 141 | 159 | 142 |
| 25 | 46.1 | 47.7 | 121 | 125 | 146 | 136 | 25 | 48.2 | 47.4 | 135 | 142 | 159 | 142 |
| 30 | 46.1 | 47.8 | 122 | 124 | 146 | 136 | 30 | 48.4 | 47.4 | 138 | 143 | 159 | 142 |
| 35 | 46.1 | 47.9 | 124 | 124 | 146 | 135 | 35 | 48.3 | 47.2 | 138 | 143 | 159 | 142 |
| 40 | 46.3 | 48.0 | 125 | 124 | 146 | 135 | 40 | 47.8 | 47.0 | 137 | 143 | 160 | 143 |
| 45 | 46.4 | 48.1 | 126 | 124 | 146 | 135 | 45 | 47.8 | 46.8 | 135 | 143 | 160 | 143 |
| 50 | 46.4 | 48.1 | 127 | 124 | 147 | 136 | 50 | 47.6 | 46.6 | 135 | 142 | 160 | 143 |
| 55 | 46.5 | 48.3 | 128 | 124 | 147 | 136 | 14 55 | 47.5 | 46.4 | 136 | 142 | 160 | 143 |
| 12 0 | 46.6 | 48.5 | 130 | 125 | 147 | 136 | 15 0 | 46.7 | 46.2 | 132 | 143 | 160 | 143 |

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The table opposite contains the values of the declination, of the horizontal and of the vertical intensity for every five minutes from $9^h$ to $15^h$ (G. M. T.) on April 17, as also the mean or "normal" values of rather quiet days before and after the eclipse, viz.: April 9, 11, 13, 21, 22, and 23; on these quiet days, from $9^h$ to $15^h$, no, or only small, disturbances are shown. The values in the table are average values for periods of five minutes, the times given being the middle of these periods. The Figure is a graphical representation of the tabular values; *D*, *H*. and *V* are the full drawn curves for April 17, and $D_m$, $H_m$ and $V_m$ the dotted mean curves for April 9, 11, 13, 21, 22, and 23. Increasing ordinates correspond to increasing west declination, increasing horizontal, and increasing vertical intensity. The times of beginning and ending of the eclipse are indicated by vertical, dotted lines.

*De Bilt, November, 1912.* G. VAN DIJK.

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## L'ECLIPSE DU 17 AVRIL 1912 À LU-KIA-PANG (CHINE).

M. Kalinowski, dans une récente communication[1] relative à l'éclipse du 17 avril dernier, manifeste le désir de voir les observations d'une station plus orientale que Varsovie. Lu-kia-pang étant dans ce cas, je vous envoie copie des courbes très calmes de ce jour. J'y joins la courbe moyenne des trois éléments à Zi-ka-wei, en avril, moyenne de onze ans, à la même échelle.

*dD.* 1 mm. = 0'.48 *dH.* 1 mm. = $\overset{\gamma}{4}.66$ *dZ.* 1 mm. = $\overset{\gamma}{7}.6$

Les heures du début et de la fin sont, en temps de la côte de Chine, $16^h\ 54^m$ et $22^h\ 15^m$.

La pensée m'était venue de faire aussi copier les courbes de l'éclipse du 10 octobre—également la nuit. Mais presque autant vaudrait tracer des lignes droites.

L'année 1912 correspond à un minimum d'activité. On peut donc s'attendre à un mouvement plus faible que notre moyenne de onze ans. Ce mouvement est en réalité si petit que je ne sais s'il est possible d'attribuer à l'éclipse l'irrégularité des minimes ondulations de *D*, *H*, et *Z*. J. DE MOIDREY, S. J.

*Lu-kia-pang, 23 novembre 1912.*

[1] *Terr. Mag.*, v. XVII, 1912, pp. 153-155.

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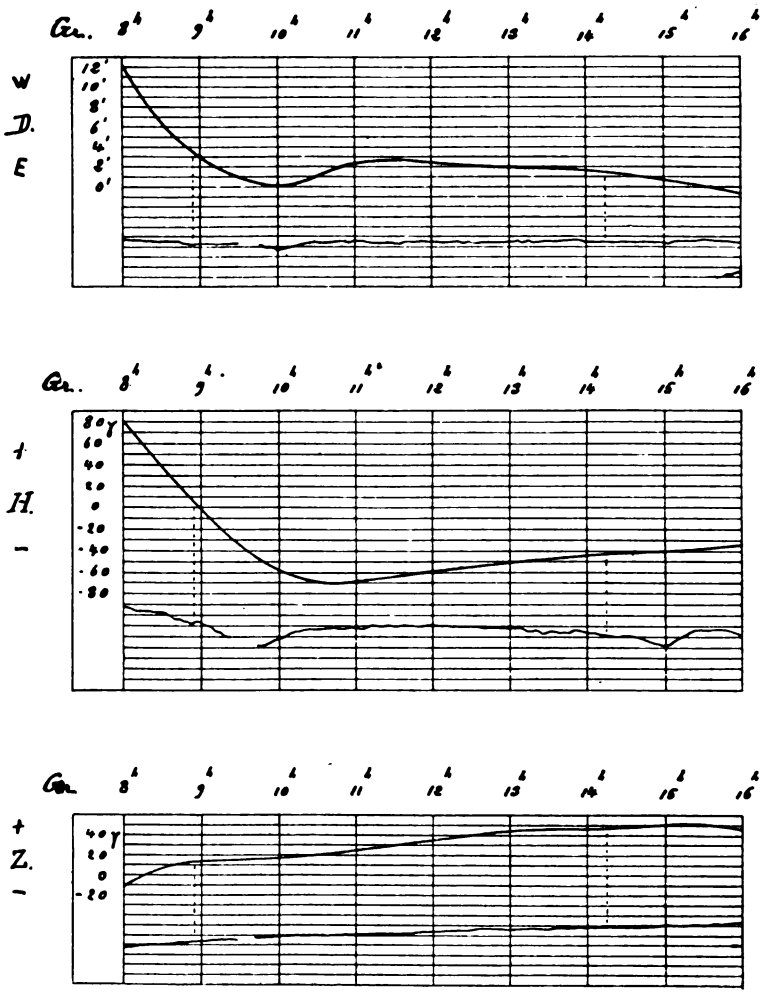


*Lu-kia-Pang, 17 Avril, 1912.*

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## MAGNETIC SURVEY WORK, DEPARTMENT OF TERRESTRIAL MAGNETISM, IN 1912.[1]

The field work accomplished by the Department during the period November 1, 1911, to October 31, 1912, in brief was as follows:

### Ocean Work.

At the end of the last fiscal year (October 31, 1911) the *Carnegie* had completed her projected circumnavigation cruise as far as Batavia, Java. She sailed from there on November 21, 1911, bound for the eastern part of the Indian Ocean, and went thence to Manila, Philippine Islands, where she arrived on February 3, 1912; the total distance covered on this leg of the cruise was 8,292 miles and the time at sea was 75.5 days. The cruise continued from Manila to Suva, Fiji; thence to Papeete, Tahiti, from which port the *Carnegie* sailed on October 15, bound for Coronel, Chile, where she arrived November 24. It is expected that the present circumnavigation cruise will be completed by the end of 1913. The total distance covered during the period described was about 28,000 nautical miles; the magnetic declination was determined at about 260 points along the tracks of the vessel, and the magnetic dip and intensity at about 180 points. [The *Carnegie* left Talcuhuano, Chile on Dec. 18 and arrived at Stanley, Falkland Islands on Jan. 27, 1913, having had a good passage in rounding the Horn, though somewhat cloudy.]

The errors in the charts of the lines of equal magnetic declination used by mariners, as disclosed by the observations on board the *Carnegie* in the eastern part of the Indian Ocean, reached nearly the same magnitude as those found in the western part of this ocean, viz., 3° to 5°, according to the chart used; the errors were again systematic. However, in the China Sea and that part of the Pacific Ocean between Manila and Suva the chart errors in magnetic declination have been gratifyingly small, usually less than 1°. The latter regions had already been partially covered by the work of the previous vessel, the *Galilee*, and the results of the observations had been supplied to the leading hydrographic establishments. On the passage from Suva to Tahiti the errors in the charts of the lines of equal magnetic declination amounted to nearly 2°.

The maximum errors in the charts of the lines of equal magnetic inclination and of equal horizontal intensity were as follows: In the eastern part of the Indian Ocean, 3.5° in magnetic dip and one-thirtieth part in the horizontal intensity; in the China Sea, 1.5° in magnetic dip and one-fortieth part in horizontal intensity; in the Pacific Ocean between Manila and Suva, 3.5° in dip and one-fourteenth part in horizontal intensity, and between Suva and Tahiti, nearly 8° in magnetic dip for one of the charts and about one-thirtieth part in horizontal intensity. It should be stated that at the date of the issue of the charts in question neither the results of the *Galilee* dip and intensity observations nor those of recent Antarctic expeditions were available.

As the cruise of the *Carnegie* is arranged so as to intersect the paths of the *Galilee*, and of other previous expeditions, as frequently as possible, valuable secular variation data are also being obtained. The generally systematic nature of the chart errors, as above noted, appear in large measure to be due to imperfect knowledge of the corrections which must be applied if past observations are to be brought up to date.

[1] From Year Book, Carnegie Institution of Washington, 1912, pp. 214–215.



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### LAND WORK.

The *land work* during the period has been chiefly in Africa, Asia, Australia, and South America. The chief expeditions were led by Dr. C. K. Edmunds in Southern China, French Indo-China, and Siam between November, 1911, and February, 1912; by Mr. E. Kidson in Western and Central Australia, including an overland trip of 1,100 miles by caravan from the railroad terminus, Oodnadatta, in South Australia, to Pine Creek, thence by rail to Port Darwin, on the north coast of Australia; by Mr. W. H. Sligh in Tripoli, Tunis, Algeria, and Morocco, and from the Canary Islands by small boat along the coast of Rio de Oro and Mauretania to St. Louis, Senegal; by Mr. D. W. Berky in Morocco, Sierra Leone, and French Guinea (on October 29 a trans-Saharan expedition, in charge of Mr. Berky, accompanied by Mr. H. E. Sawyer, left Biskra, Algieria, for Timbuktu); by Mr. J. P. Ault's party in Peru, Bolivia, and Chile. There has now been completed a series of stations across the entire continent of South America, beginning at Pará, at the mouth of the Amazon, and extending to the Pacific Coast at Callao, Peru, via the Amazon and Ucayali Rivers and Lima.

The total number of land stations at which the three magnetic elements have been determined during the fiscal year will amount to about 235; at about one-tenth of these stations more or less complete observations have been made previously, and thus data for secular variation will also be obtained.

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ABOLD, W. Geographische Ortsbestimmung im Transbaikalgebiet im Jahre 1910. Repr. Jurjev, Sitzb. Naturf.-Ges. v. 20, No. 1-2 (33 with 1 pl.). 24 cm.

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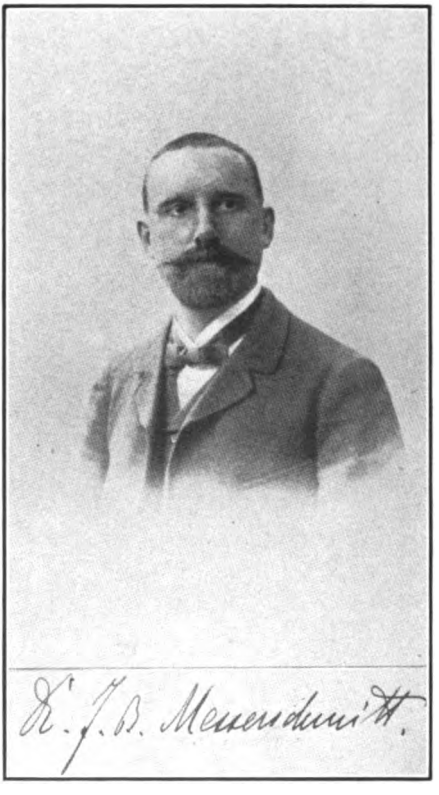


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# *Terrestrial Magnetism*
*and*
# *Atmospheric Electricity*

VOLUME XVIII JUNE, 1913 NUMBER 2


## THE C. I. W. DEFLECTOR IN USE ON THE *CARNEGIE* FOR DETERMINING THE MAGNETIC HORIZONTAL INTENSITY AND THE MAGNETIC DECLINATION AT SEA.


BY L. A. BAUER AND J. A. FLEMING.


Early in 1905, in order to supplement the Lloyd-Creak dip circle for obtaining magnetic intensities at sea, especially in low magnetic latitudes, the first of us devised a deflecting apparatus which could be readily attached to an ordinary liquid compass used in navigation, thus permitting the determination of the magnetic horizontal intensity direct, as well as of the magnetic declination.[1] This "deflector" has been used throughout the ocean work accomplished on board the *Galilee*, 1905-'08, and on the *Carnegie*, 1909-'13, by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The purpose of the present paper is to describe briefly the development of this instrument; it may be recalled that when it was first devised, Bidlingmaier's "double compass" had not yet been perfected and, even if it had been, it would not have answered our special requirements, chief among which was that of simplicity, both from the standpoint of instrumental detail and that of computation and availability of the instrument for both declination and horizontal intensity work.

Briefly described, the apparatus is an application of the sine deflection method. The deflecting magnet, instead of being mounted, however, in the same horizontal plane with the deflected magnet and off to one side, for example, to the east or to the west, as in most forms of field magnetometers and in Neumayer's "deviations-magnetometer" (used on the *Gauss*), is mounted vertically above, or below, the center of the deflected magnet system or

[1] *Ter. Mag.*, v. 11, 1906, pp. 78-83; v. 14, 1909, pp. 167-168.




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compass card. The mechanical details are such that, when the sighting device is set upon the north or south point of the compass card in equilibrium, the deflecting magnet is at right angles to the north and south diameter of the compass (assumed to define the magnetic axis of the card) and hence the principle of the simple sine deflection method is secured. The method and order of observation is such that double deflection angles are observed. If we designate the single deflection angle by $u$, the value of the horizontal intensity, $H$, is obtained by means of the formula:

$$H = \frac{mC}{\sin u}$$

where $m$ is the magnetic moment of the deflecting magnet at the time of the observation, and $C$, a quantity involving the deflecting distance and its changes with temperature, induction and distribution effects. In practice the value of $mC$ is determined at every port visited, simultaneous observations being made ashore with the deflector and the standard field magnetometer belonging to the ocean outfit. Two deflecting distances are used, as also two different magnets, so as to eliminate, as far as possible, uncertainties in the values of $mC$. The shore observations also supply the data necessary for the determination of the temperature coefficient. From a series of such port observations, the results being reduced to some standard temperature, as for example, 20° centigrade, the change in the value of $mC$ with time and magnetic field may be quickly determined by graphical methods with sufficient accuracy for sea work, if the magnets are well-seasoned ones and have received the proper care in transit from port to port.

The deflectors as used have been intended primarily for the determination of the horizontal intensity, but to provide checks against the standard declination instrument, they have been equipped with azimuth devices so as to permit securing declination observations also. In the original instruments, the Ritchie or the Negus standard azimuth attachments were used for this purpose, but in the later types, manufactured by the Department, simpler and more readily controllable azimuth devices are introduced.

The liquid type of compass has been used for all the deflectors, the liquid acting as a damping device and thus making it possible to secure settings with much greater rapidity than would be possible, for example, with a Kelvin compass. The type of deflecting magnet now used, and selected after numerous experiments with various shapes and styles, is of cylindrical form similar to those used by the Department in some of its magnetometers.

The instruments so far constructed may be designated under two classes, viz.: $A$, the type in which the deflecting magnet supports are carried on a framework rotating on the compass bowl, and the deflection angles are read directly on the card graduation; $B$, the type in which the deflecting magnet-supports form a

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permanent attachment to the bowl, the bowl itself being rotated when settings are made and the angles being read by vernier on a graduation made on the edge of the bowl. So far 4 of these instruments have been constructed, designated, respectively, Nos. 1, 2, 3, and 4.

*Deflectors Nos. 1 and 2.* These were of the type *A* and, in general, both were along the same lines of construction. For descriptions and illustrations, see references given in footnote (1). This type, used in the *Galilee* work, has been superseded by the type *B*.

*Deflector No. 3.*[2] This instrument was used on the *Carnegie* during the whole of her first cruise (1909-'10) and on her second cruise (1910-'11) as far as Cape Town, South Africa. It is of the type *B*, and was designed and constructed in the shop of the Department, utilizing the experience obtained with deflectors Nos. 1 and 2 on the *Galilee's* cruises in the Pacific Ocean. The latter work had shown some inherent defects in the instrument, due chiefly to the fact that navigation compasses already on hand had to be used for deflectors Nos. 1 and 2. Thus in a heavy sea there would at times occur a lifting of the framework carrying the deflecting magnet, and hence a momentary alteration of the deflection distance would result, and consequently a change in the constant $mC$. Various improvements were accordingly introduced in No. 3; however, as these were embodied in No. 4, now in use, they need not be enumerated here.

*Deflector No. 4.* In practice it was found that the observations had better be made with the deflecting magnet both above and below the card, and that the graduation, ordinarily found on even the best of compass cards, was not sufficiently good, and also that a continuous graduation from 0° to 360° would prove advantageous. Furthermore, the varying conditions of temperature encountered in ocean work and the accompanying unequal expansion of the various instrumental parts, would at times cause a sticking or binding of the bearing surfaces, thus making it hard to secure accurate settings. To overcome these difficulties deflector No. 4 was designed and constructed by the Department; this instrument is shown in Figs. 1, 2, 3, 4, and 5 of Plate II. In order to secure good photographs of Figs. 3 and 4 it was necessary to remove the lower deflection arm. Fig. 5 shows the instrument complete; it will be described in detail, as it is the type used on board the *Carnegie* since 1911.

It differs from deflector No. 3 chiefly in that there are now two standards or deflection arms, so that the magnet may be mounted either above or below the compass card. Each standard has provision for four corresponding deflection distances. These deflection distances are approximately the same as those in deflector No. 3, viz., 172, 182, 192, and 201 mm. The upper standard, with the exception of the clamping device for holding the deflecting magnet in position, is made in one piece and so designed that it

[2] See Fig. 1, Pl. X, *Ter. Mag.* v. 14, 1909.

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also serves in a general way to protect the sight vanes used in connection with the declination work. For avoiding parallax, two pieces are attached to the upper deflection standard, having "V" cuts placed centrally with the line of sight of the vanes; however this detail will be replaced subsequently by sights of the usual pattern with a hole and slit, the observers preferring this style.

The card graduation for this instrument (Fig. 1) is made on German silver, and is continuous from zero at the north magnetic point in a clockwise direction, as seen from above, through 360 degrees, the least count being one degree. Every ten-degree graduation is numbered, thus 1, 2, 3, 4, etc., to 35. The five-degree graduations are distinguished by somewhat greater length than single degree graduations. The diameter of the graduation of the card is 178 mm. The surface of the compass magnets and of the brass flange carrying the graduated circle, as well as the graduated surface have all been silver plated and made black, so that the graduations stand out as white lines against a black background. The bottom of the inside of the bowl has also been blackened, but the sides have been left with the bright silvered surface to provide, be reflection, suitable illumination for the graduation. The north point of the card has been marked by an arrow on the brass surface of the supporting flange and the other cardinal points were marked by means of straight lines. As in the case of deflector No. 3, the rim of the bowl is graduated into one-degree intervals, every ten-degree graduation being numbered, and is provided with two verniers which permit reading to one-tenth degree and estimation to five-hundredths degree. The diameter of this graduation is 248 mm.

The bowl, as for No. 3, has a cone bearing in its inner gimbal ring. In order, however, to effect greater ease of motion and, secondly, accuracy of setting, a ball bearing is provided, the adjustment of which is such that the cone surfaces are used for centering purposes, while the balls carry the weight of the instrument. The detail of this bearing is clearly shown in figure 2. Directly over the knife edge supports of the bearing ring are two pinions with milled heads, which may be used in finer setting of the bowl, the rack for this morion being fastened to the under side of the graduated rim. A single clamp is provided for clamping the bowl in its bearing; this clamp, however, is not for use in the sense of a slow motion in connection with the rack, but is simply intended to hold the bowl in position when necessary, and for use with the device for measuring angles between prominent objects when entering or leaving a harbor.

The arrangements for declination work with this instrument are in general similar to those of deflector No. 3. There is a long slit provided for bright line work, this mounting being set at an angle of about 55°, and a sighting wire for use in mark readings and for declination work by the shadow method. There is a universal level which is mounted at the center of the glass surface of the bowl and supported by means of arms attached at the side.

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In case the level is broken, the arrangements are such it may be quickly removed and another put in its place. When the Sun is sighted upon for determining the magnetic declination, a sharp, bright line is thrown through the slit of the inclined vane upon the surface of the glass and a setting is made by shifting the bowl so that this bright line coincides with a central line etched on the glass, the card reading being made simultaneously. When the Sun is too low for the bright line method, direct observations on the Sun may be made by sighting through the inclined vane sight, using shade glasses as necessary. The shadow of the wire of the second vane is also sometimes used. In order to facilitate using either the bright-line method or the shadow method at lower altitudes than was possible with No. 3, two ground glasses have been mounted in the frame carrying the level on which lines are etched and suitably adjusted so that, when the instrument is level, they are in the vertical plane through the sights and the etched line on the surface of the glass.

While the instrument is in use for declination and intensity work two cover plates, as shown in figure 3, have been provided, and are mounted on either side of the level support so as to cut out, when necessary, reflections from the glass surface which have been found troublesome. In order that the reflection of the opening of the wire sight may be cut off from the glass surface and not interfere with the direct reading of the card, a metal slide has been provided; there is also attached to the level supporting frame a shield in such a position that the image of the slit of the bright-line vane will not interfere with the reading of the card when using the bright-line method.

For use in measuring angles between prominent objects in entering a harbor, for example, there is a sighting ring for which a suitable bearing has been provided in the upper part of the bowl. Figure 4 shows this sighting device as mounted for use. Two opposite sides of this ring are partially cut off in order that it may be easily mounted or dismounted and a reading prism attached, by means of which the card may be read simultaneously with the sighting of the mark. The two vanes of this device are inclined in order that there may be no interference with other parts of the instrument.

The adopted scheme for the deflection observations is given below. The deflection distances, in the order of increasing magnitude, are designated for the upper standard, as U1, U2, U3, and U4, and for the lower, as L1, L2, L3, and L4. The double deflection distances are, respectively, 344, 364, 384, and 402 mm., the deflection-magnet bearings being such that the magnet-centers will be approximately equally spaced vertically on each side of the compass system. Owing, however, to the lack of symmetry of the compass magnets and the practical impossibility of aligning them absolutely under the condition of soldering necessary in construction, the eccentricity of the compass system appears to be about 3 millimeters. (In the next instrument the attempt will be made to

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simplify the compass system.) For the distances 1 and 3, the sight line is L2 to 180° and L2 to zero, and for the distances 2 and 4, L2 to 270° and L2 to 90°. Observations for horizontal intensity are made in general by using two suitable deflection distances, that is, for example, U1 and L1 together with U3 and L3. The following is the *scheme of observation* using, for example, distances 1 and 3:

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *A.* | Sight | L2 | to | 180°, | north | end | of | deflecting | magnet | east, | distance | U1 } Reading |
| *B.* | " | " | " | " | " | " | " | " | " | east, | " | L1 } same |
| *C.* | " | " | " | 0°, | " | " | " | " | " | west, | " | L1 } vernier |
| *D.* | " | " | " | " | " | " | " | " | " | west, | " | U1 } for all. |
| *E.* | " | " | " | " | " | " | " | " | " | west, | " | U3 } Reading |
| *F.* | " | " | " | " | " | " | " | " | " | west, | " | L3 } same |
| *G.* | " | " | " | 180°, | " | " | " | " | " | east, | " | L3 } vernier |
| *H.* | " | " | " | " | " | " | " | " | " | east, | " | U3 } for all. |
| *I.* | Sight | L2 | to | 0°, | north | end | of | deflecting | magnet | east, | distance | U3 } Reading |
| *J.* | " | " | " | " | " | " | " | " | " | east, | " | L3 } same |
| *K.* | " | " | " | 180°, | " | " | " | " | " | west, | " | L3 } vernier |
| *L.* | " | " | " | " | " | " | " | " | " | west, | " | U3 } for all. |
| *M.* | " | " | " | " | " | " | " | " | " | west, | " | U1 } Reading |
| *N.* | " | " | " | " | " | " | " | " | " | west, | " | L1 } same |
| *O.* | " | " | " | 0°, | " | " | " | " | " | east, | " | L1 } vernier |
| *P.* | " | " | " | " | " | " | " | " | " | east, | " | U1 } for all. |

For distances 2 and 4 the scheme is similar, using, of course, the sights as stated above. The times of beginning and ending for each distance, as well as the temperatures, are recorded. The longer deflection distances are used for the higher magnetic latitudes.

In order to avoid any drag of the magnet card, two full minutes of time are allowed after the magnet is in position at the beginning of observation for each magnet (not distance), as also between each reversal of sights, that is to say, each reversal of the bowl; one full minute of time is allowed between all other positions.

The minimum time required for half set from the beginning of reading to end would be about 8 minutes, but in general, making allowance for interruption and repetition, a determination requires some 10 minutes of time. All possible precautions are taken against setting up motion of the liquid in the bowl by sudden reversals in sights, as well as to avoid lifting the card off the pivot by the action of the deflecting magnet during reversal of the bowl, the deflecting magnet being removed during such reversals and being held sufficiently far away to have no effect. The complete set, using two distances with repetitions of readings, as may be required by the conditions of sea, is made to extend over about an hour's time, during which simultaneous dip and intensity observations are made in the forward observing house with the L. C. dip circle as modified by the Department.

Fuller publication must be deferred for the volume of Researches of the Department to contain the results of all the observations obtained on board the *Carnegie* during her two cruises, 1909-1913.

*Department of Terrestrial Magnetism,*
*Carnegie Institution of Washington.*

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Fig. 1

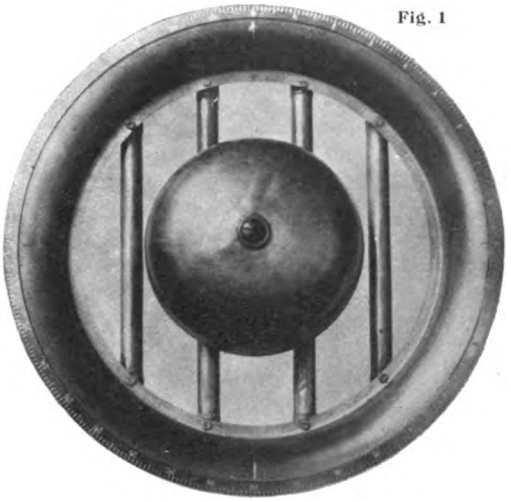


Fig. 2

Fig. 5

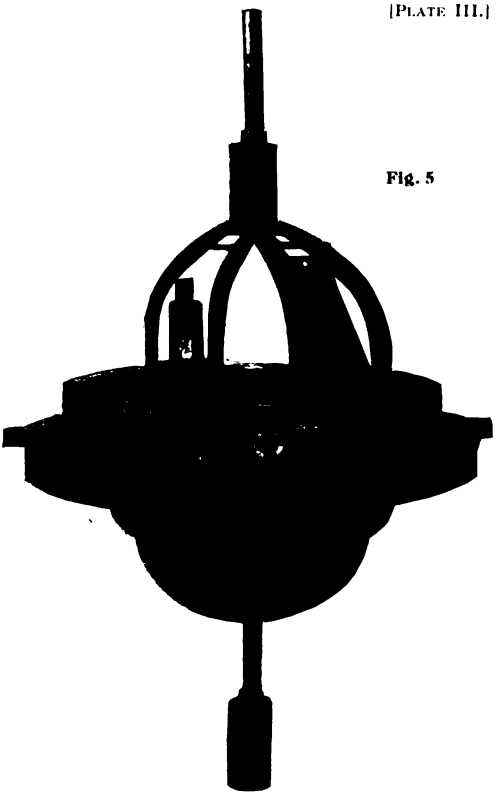
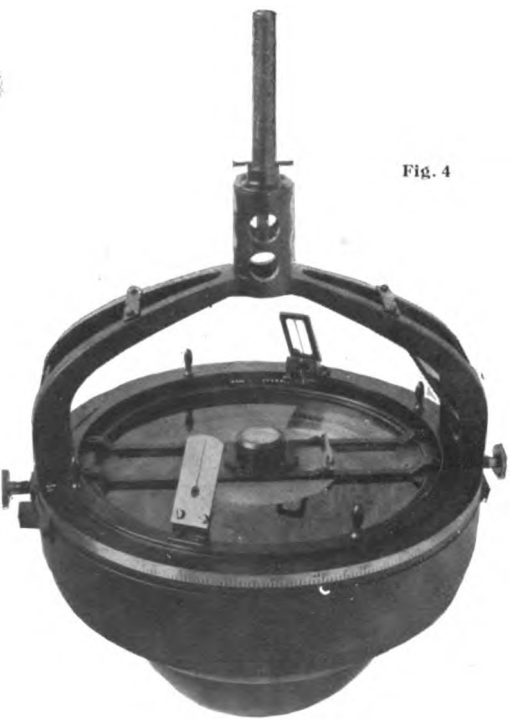


Fig. 3

Fig. 4



THE C. I. W. DEFLECTOR IN USE ON THE *Carnegie* FOR DETERMINING THE MAGNETIC HORIZONTAL INTENSITY AND THE MAGNETIC DECLINATION.

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# MAGNETIC DECLINATIONS AND CHART CORRECTIONS OBTAINED BY THE *CARNEGIE* FROM PAPEETE, TAHITI TO PORT STANLEY, FALKLAND ISLANDS, OCTOBER, 1912 TO JANUARY, 1913.[1]

By L. A. Bauer and W. J. Peters.

(*Minus sign indicates west declination, and plus, east declination.*)

A. Papeete, Tahiti, to Coronel, Chile.

| Date | Position | | Carnegie | Chart Values | | | Chart Corrections | | |
|---|---|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | Brit. | Ger. | U. S. | Brit. | Ger. | U. S. |
| 1912 | ° ′ | ° ′ | ° | ° | ° | ° | ° | ° | ° |
| Oct. 16 | 17 22 S | 150 05W | + 9.9 | + 9.9 | + 9.0 | + 9.3 | 0.0 | +0.9 | +0.6 |
| 16 | 18 01 S | 150 44W | + 9.8 | +10.0 | + 9.2 | + 9.3 | −0.2 | +0.6 | +0.5 |
| 17 | 18 48 S | 151 50W | +10.5 | +10.2 | + 9.3 | + 9.5 | +0.3 | +1.2 | +1.0 |
| 18 | 19 25 S | 153 03W | +10.4 | +10.3 | + 9.4 | + 9.6 | +0.1 | +1.0 | +0.8 |
| 18 | 20 16 S | 154 27W | +10.4 | +10.4 | + 9.6 | + 9.7 | 0.0 | +0.8 | +0.7 |
| 19 | 22 13 S | 156 42W | +10.8 | +10.8 | + 9.9 | +10.0 | 0.0 | +0.9 | +0.8 |
| 20 | 24 47 S | 158 21W | +11.8 | +11.5 | +10.4 | +10.4 | +0.3 | +1.4 | +1.4 |
| 21 | 26 21 S | 159 09W | +12.1 | +11.9 | +10.8 | +10.8 | +0.2 | +1.3 | +1.2 |
| 22 | 27 48 S | 159 10W | +12.2 | +12.2 | +11.0 | +11.0 | 0.0 | +1.2 | +1.2 |
| 26 | 35 07 S | 149 19W | +14.6 | +13.8 | +12.3 | +12.2 | +0.8 | +2.3 | +2.4 |
| 26 | 35 16 S | 148 23W | +14.6 | +13.9 | +12.4 | +12.3 | +0.7 | +2.2 | +2.3 |
| 27 | 36 06 S | 145 20W | +14.7 | +14.1 | +12.8 | +12.7 | +0.6 | +1.9 | +2.0 |
| 28 | 36 34 S | 143 37W | +15.0 | +14.3 | +13.0 | +12.9 | +0.7 | +2.0 | +2.1 |
| 28 | 36 48 S | 142 18W | +14.8 | +14.4 | +13.1 | +13.0 | +0.4 | +1.7 | +1.8 |
| 29 | 37 05 S | 140 23W | +14.8 | +14.5 | +13.4 | +13.2 | +0.3 | +1.4 | +1.6 |
| 29 | 37 18 S | 138 14W | +14.8 | +14.6 | +13.6 | +13.5 | +0.2 | +1.2 | +1.3 |
| 30 | 37 28 S | 135 42W | +15.0 | +14.8 | +13.8 | +13.9 | +0.2 | +1.2 | +1.1 |
| 31 | 37 35 S | 134 47W | +15.4 | +14.9 | +14.0 | +14.0 | +0.5 | +1.4 | +1.4 |
| 31 | 37 44 S | 133 52W | +15.4 | +15.0 | +14.2 | +14.2 | +0.4 | +1.2 | +1.2 |
| Nov. 1 | 38 02 S | 132 29W | +15.9 | +15.2 | +14.4 | +14.5 | +0.7 | +1.5 | +1.4 |
| 2 | 38 16 S | 131 18W | +16.0 | +15.4 | +14.8 | +14.8 | +0.6 | +1.2 | +1.2 |
| 3 | 38 35 S | 129 49W | +16.1 | +15.6 | +15.1 | +15.1 | +0.5 | +1.0 | +1.0 |
| 3 | 38 53 S | 127 59W | +16.2 | +15.9 | +15.5 | +15.4 | +0.3 | +0.7 | +0.8 |
| 4 | 39 08 S | 126 25W | +16.2 | +16.1 | +15.8 | +16.0 | +0.1 | +0.4 | +0.2 |
| 4 | 39 23 S | 124 48W | +16.1 | +16.4 | +16.2 | +16.4 | −0.3 | −0.1 | −0.3 |
| 5 | 39 28 S | 123 52W | +17.0 | +16.5 | +16.5 | +16.6 | +0.5 | +0.5 | +0.4 |
| 5 | 39 34 S | 122 14W | +17.4 | +16.7 | +16.2 | +17.0 | +0.7 | +0.6 | +0.4 |
| 6 | 39 38 S | 120 02W | +17.6 | +17.0 | +17.4 | +17.5 | +0.6 | +0.2 | +0.1 |
| 7 | 39 36 S | 115 01W | +18.0 | +17.5 | +18.5 | +18.6 | +0.5 | −0.5 | −0.4 |
| 8 | 39 35 S | 111 42W | +17.9 | +18.0 | +19.2 | +19.4 | −0.1 | −1.3 | −1.5 |
| 10 | 39 56 S | 109 33W | +19.0 | +18.3 | +19.9 | +20.0 | +0.7 | −0.9 | −1.0 |
| 12 | 41 23 S | 104 40W | +21.2 | +19.5 | +21.6 | +21.6 | +1.7 | −0.4 | −0.4 |
| 14 | 42 56 S | 98 54W | +22.1 | +21.1 | +23.2 | +23.2 | +1.0 | −1.1 | −1.1 |
| 15 | 41 52 S | 96 53W | +21.7 | +21.0 | +22.8 | +22.9 | +0.7 | −1.1 | −1.2 |
| 16 | 41 36 S | 96 01W | +21.5 | +21.0 | +22.8 | +22.8 | +0.5 | −1.3 | −1.3 |
| 17 | 41 15 S | 95 36W | +21.5 | +20.9 | +22.7 | +22.7 | +0.6 | −1.2 | −1.2 |
| 17 | 41 08 S | 95 26W | +21.5 | +20.9 | +22.6 | +22.6 | +0.6 | −1.1 | −1.1 |
| 19 | 43 18 S | 90 49W | +22.4 | +21.7 | +23.0 | +23.1 | +0.7 | −0.6 | −0.7 |
| 20 | 44 07 S | 88 14W | +22.6 | +21.8 | +23.0 | +23.1 | +0.8 | −0.4 | −0.5 |
| 22 | 41 24 S | 80 19W | +19.0 | +19.1 | +19.5 | +19.8 | −0.1 | −0.5 | −0.8 |
| 23 | 40 18 S | 78 56W | +18.8 | +18.4 | +18.5 | +19.0 | +0.4 | +0.3 | −0.2 |
| 23 | 39 12 S | 77 35W | +18.8 | +17.8 | +17.7 | +18.2 | +1.0 | +1.1 | +0.6 |
| 24 | 38 28 S | 76 43W | +18.3 | +17.4 | +17.1 | +17.8 | +0.9 | +1.2 | +0.5 |
| 24 | 37 47 S | 75 29W | +18.4 | +16.8 | +16.4 | +17.1 | +1.6 | +2.0 | +1.3 |

[1] For previous tables see *Terr. Mag.*, v. 15, pp. 57-82, 129-144; v. 16, pp. 133-136; v. 17, pp. 31-32, 97-101, 141-144, 179-180.



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B. Coronel, Chile, to Port Stanley, Falkland Islands.

| Date | Position | | Carnegie | Chart Values | | | Chart Corrections | | |
|---|---|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | Brit. | Ger. | U. S. | Brit. | Ger. | U. S. |
| 1912 | ° ′ | ° ′ | ° | ° | ° | ° | ° | ° | ° |
| Dec. 20 | 35 18 S | 74 40W | +15.8 | +16.0 | +15.5 | +16.1 | —0.2 | +0.3 | —0.3 |
| 20 | 33 45 S | 76 37W | +15.8 | +16.2 | +15.8 | +16.4 | —0.4 | 0.0 | —0.6 |
| 21 | 31 35 S | 79 32W | +16.3 | +16.3 | +16.2 | +16.7 | 0.0 | +0.1 | —0.4 |
| 22 | 31 04 S | 80 12W | +16.5 | +16.3 | +16.3 | +16.6 | +0.2 | +0.2 | —0.1 |
| 23 | 29 53 S | 81 42W | +16.1 | +16.2 | +16.2 | +16.5 | —0.1 | —0.1 | —0.4 |
| 24 | 27 43 S | 85 53W | +15.8 | +15.8 | +16.6 | +16.6 | 0.0 | —0.8 | —0.8 |
| 26 | 26 21 S | 90 21W | +15.5 | +15.4 | +16.9 | +16.6 | +0.1 | —1.4 | —1.1 |
| 27 | 25 56 S | 92 29W | +15.1 | +15.3 | +16.8 | +16.7 | —0.2 | —1.7 | —1.6 |
| 28 | 25 49 S | 93 18W | +15.0 | +15.2 | +16.8 | +16.7 | —0.2 | —1.8 | —1.7 |
| 28 | 25 43 S | 93 53W | +14.9 | +15.2 | +16.8 | +16.8 | —0.3 | —1.9 | —1.9 |
| 30 | 25 51 S | 95 13W | +15.4 | +15.2 | +16.8 | +16.8 | +0.2 | —1.4 | —1.4 |
| 31 | 26 57 S | 96 34W | +14.9 | +15.5 | +17.2 | +17.2 | —0.6 | —2.3 | —2.3 |
| 1913 | | | | | | | | | |
| Jan. 1 | 27 24 S | 97 38W | +15.5 | +15.6 | +17.3 | +17.4 | —0.1 | —1.8 | —1.9 |
| 2 | 27 56 S | 98 48W | +15.4 | +15.6 | +17.3 | +17.4 | —0.2 | —1.9 | —2.0 |
| 3 | 29 22 S | 100 14W | +15.7 | +16.0 | +17.7 | +17.9 | —0.3 | —2.0 | —2.2 |
| 4 | 30 28 S | 101 24W | +16.2 | +16.2 | +18.0 | +18.1 | 0.0 | —1.8 | —1.9 |
| 5 | 31 07 S | 101 58W | +16.7 | +16.3 | +18.1 | +18.1 | +0.4 | —1.4 | —1.4 |
| 6 | 32 44 S | 103 32W | +17.0 | +16.8 | +18.5 | +18.6 | +0.2 | —1.5 | —1.6 |
| 6 | 33 40 S | 104 24W | +17.6 | +17.0 | +18.6 | +18.8 | +0.6 | —1.0 | —1.2 |
| 7 | 34 30 S | 105 07W | +18.2 | +17.1 | +18.9 | +19.0 | +1.1 | —0.7 | —0.8 |
| 9 | 38 00 S | 107 36W | +18.8 | +18.0 | +19.7 | +19.8 | +0.8 | —0.9 | —1.0 |
| 10 | 39 09 S | 107 38W | +18.8 | +18.3 | +20.1 | +20.1 | +0.5 | —1.3 | —1.3 |
| 10 | 40 21 S | 107 17W | +20.0 | +18.8 | +20.7 | +20.7 | +1.2 | —0.7 | —0.7 |
| 11 | 42 41 S | 105 55W | +21.5 | +19.8 | +22.0 | +22.0 | +1.7 | —0.5 | —0.5 |
| 12 | 44 52 S | 102 25W | +22.5 | +21.4 | +23.6 | +23.7 | +1.1 | —1.1 | —1.2 |
| 13 | 45 39 S | 100 59W | +23.5 | +22.0 | +24.1 | +24.2 | +1.5 | —0.6 | —0.7 |
| 13 | 46 40 S | 99 17W | +24.1 | +22.9 | +25.0 | +24.8 | +1.2 | —0.9 | —0.7 |
| 14 | 46 47 S | 99 39W | +24.1 | +22.9 | +25.0 | +24.8 | +1.2 | —0.9 | —0.7 |
| 18 | 51 47 S | 91 07W | +25.5 | +25.2 | +26.4 | +26.6 | +0.3 | —0.9 | —1.1 |
| 18 | 51 56 S | 90 26W | +25.8 | +25.1 | +26.2 | +26.5 | +0.7 | —0.4 | —0.7 |
| 19 | 52 05 S | 89 46W | +25.8 | +25.1 | +26.2 | +26.5 | +0.7 | —0.4 | —0.7 |
| 20 | 53 47 S | 86 18W | +25.4 | +25.0 | +26.0 | +26.5 | +0.4 | —0.6 | —1.1 |
| 24 | 56 04 S | 66 23W | +17.3 | +17.2 | +17.2 | +17.3 | +0.1 | +0.1 | 0.0 |
| 25 | 55 41 S | 64 05W | +15.6 | +15.9 | +15.7 | +16.0 | —0.3 | —0.1 | —0.4 |

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# UEBER DIE GEGENSEITIGE EINWIRKUNG ZWEIER MAGNETE IN BELIEBIGER LAGE. (Schluss.)

*Von* AD. SCHMIDT *in Potsdam.*

## Korrektionen für Lagenabweichungen.

Die Voraussetzungen, die den in der Praxis vorwiegend benutzten speziellen Fällen zu Grunde liegen, sind natürlich nie streng erfüllt. Man muss daher noch den Einfluss der möglichen Abweichungen untersuchen, einerseits, um festzustellen, unter welchen Bedingungen dieser Einfluss unmerklich ist, andererseits, um ihn eliminieren oder durch Korrektionen unschädlich machen zu können, wenn er nicht mehr vernachlässigt werden darf. Dazu muss man natürlich auf die allgemeinen Formeln zurückgreifen, und gerade darin liegt ein Hauptgrund dafür, dass man diese ableiten muss, obgleich anscheinend spezielle Formeln für alle praktischen Aufgaben genügen. Dieser Umstand hat keineswegs immer die gebührende Beachtung gefunden, und es ist ein besonderes Verdienst der Arbeit von L e y s t , dass diese darauf ausführlich und mit grundsätzlicher Betonung eingeht. (A. a. O., S. 124 ff.) In der Durchführung des Gedankens bleibt sie allerdings auf halbem Wege stehen, indem sie die Voraussetzung dauernd beibehält, dass beide Magnete genau in derselben, zur Drehungsachse der Nadel senkrechten Ebene liegen.

In zweifacher Hinsicht sind nun Abweichungen von den Annahmen der speziellen Fälle möglich: bei der Beschaffenheit der Magnete und bei ihrer Lage. Für jenes kommt im wesentlichen nur eine nicht vollkommen reguläre Magnetisierung von Stab und Nadel in Betracht. Die wichtigsten hierbei bestehenden Möglichkeiten sind schon im Vorhergehenden behandelt worden. Für die Abweichungen der gegenseitigen Lage von dem vorausgesetzten Idealzustande liessen sich in ähnlicher Weise in jedem einzelnen Falle Korrektionen angeben. Hier mag es der Kürze halber genügen, zwei Beispiele anzuführen, die sich auf die praktisch besonders wichtige erste Lamont'sche Hauptlage beziehen.

1) Die verlängerte Achse des Stabes treffe nicht den in der Drehungsachse angenommenen Mittelpunkt der Nadel, sondern dieser liege um den gegen $e$ sehr kleinen Betrag $a$ seitwärts und um den ebenfalls kleinen Betrag $c$ oberhalb von ihr. Ferner stehe die Achse der Nadel nicht genau senkrecht auf der des Stabes,



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sondern bilde mit ihr den von einem rechten nur sehr wenig abweichenden Winkel $\left(\frac{\pi}{2} - \nu\right)$. (Nicht in Betracht zu ziehen braucht man die Abweichungen der beiden magnetischen Achsen von der Horizontalen, wenn man mit den effektiven Momenten operiert, da die Drehungsachse der frei beweglichen Nadel sehr genau vertikal ist und das Lager des Stabes leicht ebenso genau horizontal gestellt werden kann.)

Man sieht ohne weiteres ein, dass die gegenseitige Lage der Magnete hiernach durch die Grössen $\eta = \frac{\pi}{2} + \frac{c}{e}$, $\beta = \pi + \sigma$ mit $\sin \sigma = \frac{a}{e}$, $\phi = \frac{\pi}{2} - \nu + \sigma$ definiert ist, während zugleich $e^2 + c^2$ für $e^2$ einzutreten hat und $\psi = \frac{\pi}{2}$ ist. Es wird im allgemeinen genügen, die hieraus entspringende Korrektion nur so weit zu berechnen, als sie von den Hauptparametern $M_1$ und $M_1'$ abhängt, so dass nur das erste Glied der Formel (52) zu berücksichtigen ist, die der Einfachheit halber sogleich in der für $X$ gültigen Gestalt (52a) benutzt werden möge. Man hat also $-\frac{3}{2} M_1 M_1' e^{-3} \left(1 + \frac{c^2}{e^2}\right)^{-\frac{3}{2}}$ ([10; 11] + [11; 11]) zu bilden. Darin fällt indessen noch [10; 11] fort, weil es den Faktor $P^{10}(\cos \psi)$, d. i. $\cos \psi$, enthält, und es bleibt nur

$$[11; 11] = P^{22}(\cos \eta) \sin (\beta + \phi) + P^{20}(\cos \eta) \sin (\beta - \phi)$$
$$= -\sin \eta^2 \cos (\nu - 2\sigma) + \left(\cos \eta^2 - \frac{1}{3}\right) \cos \nu$$

einzusetzen. Die Ausrechnung bis zu Ausdrücken 2. Ordnung in den kleinen Grössen $a : e$, $c : e$, $\nu$ gibt

$$2 M_1 M_1' e^{-3} \left(1 - 3\frac{c^2}{e^2} - \frac{3}{2}\frac{a^2}{e^2} + \frac{3}{2}\frac{a}{e}\nu - \frac{1}{2}\nu^2\right)$$

Somit ist die dem Ausdruck in Formel (68) hinzuzufügende Korrektion

$$\partial X = -M_1 M_1' e^{-3} \left(6\frac{c^4}{e^2} + 3\frac{a^2}{e^2} - 3\frac{a}{e}\nu + \nu^2\right) \tag{76}$$

2) Der magnetische Mittelpunkt der Nadel liege nicht auf ihrer Drehungsachse, sondern um das Stück $a$ in der Richtung nach dem Nordpol hin verschoben. Man kann hier ähnlich wie im vorigen Falle verfahren, wenn man beachtet, dass das Drehungsmoment bei irgend einer Lage der Nadel von der Lage der Drehungsachse unabhängig ist. Einfacher noch ergibt sich indessen die Lösung, wenn man den Anfangspunkt in die Dre-

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hungsachse verlegt, auf die sich die Koordinaten der gegenseitigen Lage $(e, \beta, \phi)$ beziehen. Sind $M_1'$, $M_3'$ . . . die Parameter der als regulär angenommenen Nadel in Bezug auf ihren Mittelpunkt, so bleibt, wie sich aus (10) leicht ergibt, $M_1'$ bei dieser Verlegung ungeändert, aus $M_3'$ wird $M_3' + 3a^2 M_1'$, und $M_2'$, das vorher nicht auftrat, erhält den Wert $2aM_1'$.

Ein Blick auf Formel (68) zeigt, dass unter diesen Bedingungen zu $X$ die Korrektion $-6M_1 e^{-5} \cdot 3a^2 M_1'$, d. i. $-18 M_1 M_1' a^2 e^{-5}$ tritt. Ebenso einfach lässt sich übrigens das Resultat für den allgemeineren Fall der 1. Gauss'schen Hauptlage aus (67) und (64) ablesen. Hier wird die Korrektion

$$\frac{9}{2} M_1 e^{-4} \sigma_2 \cdot 2a M_1' + \frac{3}{2} M_1 e^{-5} (\sigma_1 + 5\sigma_3) \cdot 3a^2 M_1' =$$
$$\frac{9}{2} M_1 M_1' e^{-3} \left[ 2\frac{a}{e} \sin 2\phi + \frac{a^2}{e^2} (\sin \phi + 5 \sin 3\phi) \right]$$

Wird von den beiden Magneten nur vorausgesetzt, dass sie sich in derselben Ebene befinden, so ergibt sich die Wirkung von $M_1$ auf $M_2'$ nach (50) und (52a) zu $-\frac{15}{4} M_1 M_2' e^{-4} ([10;22] + [11;22])$.

Hierin verschwindet $[10; 22]$, weil $\psi = \frac{\pi}{2}$ ist, und es bleibt

$$-\frac{15}{2} M_1 M_1' a e^{-4} \left( \sin (\beta + 2\phi) - \frac{1}{5} \sin (\beta - 2\phi) \right) =$$
$$-3 M_1 M_1' a e^{-4} (2 \sin \beta \cos 2\phi + 3 \cos \beta \sin 2\phi)$$

Dazu tritt noch als Folge der Aenderung von $M_3'$ um $3a^2 M_1'$ nach (55) der Betrag

$$-3 M_1 M_1' a^2 e^{-5} \left( \frac{3}{2} c_1 \sigma_1 + \frac{3}{8} s_1 \gamma_1 + \frac{15}{2} c_1 \sigma_3 + \frac{45}{8} s_1 \gamma_3 \right)$$

Die Gesamtkorrektion, die für $\beta = \pi$ und $\phi = \frac{\pi}{2}$ natürlich wieder die vorhergehenden speziellen Werte annimmt, wird also

$$(77) \quad \partial X = -M_1 M_1' e^{-3} \left[ 3\frac{a}{e} (2 \sin \beta \cos 2\phi + 3 \cos \beta \sin 2\phi) \right.$$
$$\left. + \frac{9}{8}\frac{a^2}{e^2} \left\{ \sin \beta (\cos \phi + 15 \cos 3\phi) + 4 \cos \beta (\sin \phi + 5 \sin 3\phi) \right\} \right]$$

Diesen allgemeinen Fall hat auch Leyst (auf S. 154-159 seiner Schrift) behandelt. Die in seiner Formel (62) auftretenden Korrektionsglieder lauten unter Verbesserung eines kleinen Versehens (in der vorletzten Zeile muss $3x^2$ statt $2x^2$ stehen) in der

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hier benutzten Schreibweise (vgl. Anm. 26; ferner ist sein $x$ dasselbe, was hier $a$ heisst)

$$-M_1 M_1' e^{-3}\left[6\frac{a}{e}(-\cos\phi\sin\triangle+\sin\phi\cos\triangle-5\sin\phi\cos\phi\cos\beta)\right.$$
$$-\frac{9}{2}\frac{a^2}{e^2}(\sin\triangle-5\sin\triangle\cos\phi^2+10\cos\triangle\sin\phi\cos\phi$$
$$\left.+5\sin\phi\cos\beta-35\sin\phi\cos\phi^2\cos\beta)\right|$$

Man überzeugt sich leicht, dass dieser Ausdruck mit demjenigen in der vorstehenden Formel (77) identisch ist. Ebenso stimmen seine speziellen Angaben für die 1. Hauptlage in Gleichung (63) und (65) mit den hier zuvor abgeleiteten überein, wenn die infolge des erwähnten und eines weiteren Versehens ungenauen Koeffizienten von $x^2$ verbessert werden. Richtiggestellt lauten sie $-9\ (1-5\sin\psi^2)$ und $-9$, wie man leicht aus der allgemeinen Formel ableitet.

Die translatorischen Kräfte und die übrigen Drehungsmomente.

Es ist schon an früherer Stelle erwähnt worden, dass die hier wie auch sonst stets gewählte Form des Potentialausdrucks dem Umstande Rechnung trägt, dass in den Anwendungen fast ausschliesslich das zur Koordinate $\phi$ gehörige Drehmoment gebraucht wird. Während sich daher diese Grösse (ebenso wie übrigens auch die in die Richtung von $e$ fallende Kraft) unmittelbar aus V ablesen lässt, erfordert die Ableitung der übrigen Kräfte und Momente auf dem nächstliegenden Wege—d. h. durch Differentiation nach den Lagekoordinaten $e$, $\psi$, $\beta$ u. s. w.—ziemlich umständliche Rechnungen. Durch einen einfachen Kunstgriff—indem man nämlich die Differentiation auf die Parameter schiebt—lässt sich indessen diese Ableitung wesentlich vereinfachen und vor allem übersichtlicher gestalten.

Ich muss mich hier darauf beschränken, dieses Verfahren, das auch schon im zweiten Falle des vorhergehenden Abschnitts zur Anwendung kam, an einem Beispiel zu veranschaulichen. Es handle sich darum, unter der Voraussetzung regulärer Magnete die in der Richtung der magnetischen Nadelachse wirkende Kraftkomponente zu berechnen. Aendert sich V um $v$, wenn die Nadel in der bezeichneten Richtung um die kleine Grösse $a$ verschoben wird, so ist die gesuchte Kraft $A = -\operatorname{Lim}(v:a)_{a=o}$. Bezieht man nun in der neuen Lage die Parameter der Nadel auf den alten, um $a$ zurückliegenden Anfangspunkt, so geht $M_n'$ nach (10) in

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$M'_n + na\,M'_{n-1}$ über. Daraus folgt sofort, dass man A aus V erhält, wenn man in diesem statt $M'_n$ überall $-n\,M'_{n-1}$ setzt. Als erstes Glied der Entwickelung bei beliebiger Lage der Magnete in derselben Ebene erhält man so nach (60)

$$A = \frac{3}{2} M_1 M_1' e^{-4} (c_1 + 3c_1\gamma_2 - 2 s_1 \sigma_2) \tag{78}$$

Die zur Nadelachse senkrechte, in dieselbe Ebene fallende Komponente $B$ findet man am bequemsten, indem man zunächst die nach $e$ gerichtete Kraft $E$ berechnet. Gilt diese in der Richtung wachsender Werte von $e$ als positiv und ist $B$ im Sinne des zunehmenden Winkels $\phi$ über $A$ hinaus gelegen, so hat man $E = -A\cos\phi + B\sin\phi$ oder $B = (A\gamma_1 + E) : \sigma_1$. Nun ist nach (54)

$$E = -\frac{\partial V}{\partial e} = 3 M_1 M_1' e^{-4} (-2 c_1\gamma_1 + s_1\sigma_1) \tag{79}$$

woraus sich sofort

$$B = -\frac{3}{2} M_1 M_1' e^{-4} (3 c_1\sigma_2 + 2 s_1\gamma_2) \tag{80}$$

ergibt. Die dritte, zur gemeinsamen Ebene senkrechte Kraftkomponente $C$ verschwindet natürlich im vorliegenden Fall aus Symmetriegründen. Dasselbe gilt von den Drehmomenten um die beiden horizontalen Achsen.

Die Verlegung des Koordinatenursprungs kann übrigens auch benutzt werden, um die Anwendung der vorausgehenden Entwickelungen im Falle einer sehr geringen Entfernung der beiden Magnete zu ermöglichen, wie ein solcher beispielsweise bei dem Lloyd-Creak-Apparat vorliegt.

### Die Bestimmung der Parameter eines Magnets.

Kennt man die Parameter zweier Magnete, so kann man mit Hilfe der vorausgehenden Formeln für jede gegenseitige Lage ihre Einwirkung auf einander berechnen. Die Bestimmung dieser Parameter wird damit zu einer grundlegenden Aufgabe, zu deren Lösung natürlich dieselben Hilfsmittel ausreichen. Man hat dazu nur nötig, jene Einwirkung für eine Anzahl zweckmässig ausgewählter Lagen empirisch zu messen, um daraus die als Konstanten in die Gleichungen eingehenden Parameter abzuleiten. Diese Aufgabe—eine Erweiterung der bisher so gut wie ausschliesslich behandelten Bestimmung des Moments und der Poldistanz—kann hier nicht mehr erörtert werden; ihre systematische Behandlung muss einer besonderen Arbeit vorbehalten bleiben. Nur auf zwei allgemeine Punkte mag kurz hingewiesen werden.

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Bei näherer Betrachtung der Formeln für das Drehungsmoment sieht man, dass meistens die höheren Parameter des abgelenkten Magnets mit grösseren Zahlenkoeffizienten behaftet sind, als die gleich hohen des ablenkenden. Wenn die zwei Magnete nicht von sehr verschiedener Grösse sind, ist es daher im allgemeinen besser, denjenigen, dessen Parameter man messen will, nicht als Stab, sondern als Nadel zu verwenden. Noch mehr empfiehlt es sich freilich, falls man nicht etwa die Konstanten des einen schon genau kennt, das eine wie das andere zu tun, also unter Vertauschung der beiden Magnete zu beobachten. Zu einem besonderen Zwecke (um die Differenz der Poldistanzen mehrerer annähernd gleicher Magnete zu ermitteln[29]) hat C h r e e einmal von diesem Verfahren Gebrauch gemacht.

Der eine Magnet, am zweckmässigsten der ablenkende, lässt sich oft mit Vorteil durch einen Stromkreis oder eine Kombination von solchen ersetzen. Man ist dadurch in den Stand gesetzt, ein magnetisches Feld von beliebig vorgeschriebener, exakt angebbarer Form herzustellen, dessen Einwirkung auf den hinein gebrachten Magnet demgemäss auch leicht bestimmten Aufgaben angepasst werden kann.[30] So lassen sich beispielsweise mannigfache Nullmethoden angeben, die es gestatten, das Verhältnis jedes einzelnen Parameters zum Moment unabhängig von den übrigen zu bestimmen. Die Messung dieser anscheinend recht konstanten Verhältnisse ist von grosser Bedeutung für die Verschärfung der Methoden zur Ermittelung des magnetischen Moments.

*Corrigenda (Bd. 17).*

S. 184, 11. Z. v. o.: lies benutzt statt enutzt.
S. 191, 9. Z. v. u.: lies a. a. O statt a. a. $\theta$; 6. Z. v. u. lies: $L^2$ statt $l^2$.
S. 191, 1. Z. v. u.: lies $\bar{a}^4$: $a^4$ auf; dabei ist $a$ das, u. s. w.
S. 193, 8. Z. v. u.: lies $\frac{\partial \Pi}{\partial r} = \frac{\partial \Pi'}{\partial r}$ $\frac{\partial \Pi}{r \partial \sigma} = \frac{\partial \Pi'}{r \partial \sigma}$
S. 194, 11. Z. v. o.: lies $l_0^2 = M_3$: $M_1$ bei kleinem $l_0$: $r_0$.
S. 194, 13. Z. v. u.: lies angesetzt und unter der, u. s. w.
S. 199, 12. Z. v. u.: lies Versuchen für $\mu$ statt Versuchen für $\mu$.
S. 200, 11. Z. v. o.: lies $m\, a_0^2$ statt $n\, a_0^2$; 12. Z. v. u.: lies 10 statt 16.
S. 210, Fig. 1: $\eta$ ist der Winkel $Z'O'O$ statt $O\,O'\,O$.
S. 216, 2. Z. v. u.: lies 7. Ordnung statt 5. Ordnung.
S. 217, 15. Z. v. o.: lies (77; 11) statt 77:11).
S. 218, 14. Z. v. u.: lies $K_{nr}$ statt $Knr$.
S. 231, 12. Z. v. u.: lies $\frac{45}{2}$ statt $\frac{45}{4}$.

[29] C. CHREE: The law of action between magnets and its bearing on the determination of the horizontal component of the Earth's magnetic force with unifilar magnetometers. *Phil. Mag.*, Vol. VI. No. 44. 1904.

[30] Dieser naheliegende Gedanke scheint bisher wenig Beachtung gefunden zu haben. Die einzige mir bekannte Anwendung gab kürzlich J. M. MILLER: Determination of the Pole Distance of a very small magnet. *Terr. Mag.*, Vol. XVII. S. 42. 1912.

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# EINIGE BESTIMMUNGEN DER AKTIVITÄT DER LUFT IN DER NÄHE DER SÜDCHILENISCHEN UND ARGENTINISCHEN KÜSTE.

VON WALTER KNOCHE.

Von der Leitung des Department of Terrestrial Magnetism (Carnegie Institution of Washington) beauftragt, luftelektrische Messungen während der totalen Sonnenfinsternis im Staate Minas Geraes (Brasilien—10. Okt. 1912) auszuführen, bot sich mir—die Kordillereneisenbahn war wegen gewaltiger Schneefälle ausser Betrieb—willkommene Gelegenheit, auf der Dampferfahrt nach Rio einige Messungen der induzierten Aktivität der Luft auszuführen. Während ich im März-Mai 1911 Gelegenheit hatte, derartige Bestimmungen auf einer Fahrt nach der Osterinsel,[1] also in landfernen Gebieten zu machen, kamen diesmal küstennahe Gewässer in Frage. Um eine Vergleichbarkeit dieser Messungen mit den erwähnten zu erreichen, wurde ganz in der gleichen Weise mit dem gleichen Instrument gearbeitet (auf der Brücke des P. M. S. *Oronsa*); ich brauche daher die Art der Messung hier nicht wiederholen.

Die Tabelle auf Seite 72 enthält in der ersten Spalte den ungefähren Schiffsort während der Beobachtung nach der Kartenskizze; sie enthält ferner das Datum, die Zeit der Exposition, den Elster und Geitelschen Wert $A$ für 3 Min. nach Beendigung der Ladung, die Entfernung vom nächsten Landpunkt in km, Windrichtung und Stärke (Beaufort) und schliesslich für einige Fälle das Resultat der Kurvenanalyse, d. h. den prozentualen Gehalt an Radium und Thoriuminduktionen.

Die erhaltenen $A$-Werte zeigen trotz ihrer geringen Zahl beträchtliche Schwankungen zwischen 2.4 (Ort 9) und 309.0 (Ort 14); das Mittel aller 18 Beobachtungen ist 111.1. Vergleicht man hiermit die landfernen Osterinselwerte, so findet man eine weit geringere Variabilität, nämlich ein Maximum 8.5 und ein Minimum von 0.9; das Mittel ist 31 mal kleiner, $A = 3.6$ (19 Beobachtungen). Auch auf der Osterinselfahrt steigen die Werte bei Annäherung ans Land, in etwa 550 km davon finden wir den Wert 10.9, in 180 km Küstenentfernung $A = 77$. Diese Verhältnisse be-

[1] *Physikalische Zeitschrift*, 1912, S. 152-158.



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weisen einfach wiederum die terrigene Herkunft der aktiven Materien. Vergleichen wir das Mittel von 5 Westküstenbeobachtungen (Pazifik) mit 11 Ostküstenbeobachtungen (Atlantik), so sind diese ziemlich gleich, nämlich *A* einmal gleich 120.6, im zweiten Fall gleich 117.9. Diese Gleichheit ist aber nur scheinbar, da die mittlere Küstenentfernung bei der Fahrt durch den Stillen Ozean etwa 47 km, durch den Atlantischen 156 km betrug. Bei der mehr als 3 mal grösseren Landweite in letztem Falle, sollten die *A*-Werte

| Ort nach Skizze | Datum 1912 | Zeit | A für 3 Min. | Kürzeste Entfernung Land (km) | Wind-Richtung und Stärke (Beaufort) | Ra: Th (?) |
|---|---|---|---|---|---|---|
| 1 | 13 Sept. | 9a-11a | 9.6 | 69 | W3 | 100:0 |
| 2 | 13 Sept. | 1p-3p | 183.6 | 46 | NNW4 | |
| 3 | 13 Sept. | 5p-7p | 244.8 | 37 | WNW4 | |
| 4 | 13 Sept. | 10p-MN | 102.0 | 44 | NNW4 | |
| 5 | 14 Sept. | 9a-11a | 63.0 | 37 | NW3 | 100:0 |
| 6 | 15 Sept. | 6a-8a | 72.0 | Mag. Strasse | NNE7 | |
| 7 | 15 Sept. | 3p-5p | 27.6 | Mag. Strasse | NNW5 | 97:3 |
| 8 | 16 Sept. | 8a-10a | 37.2 | 130 | WNW5 | |
| 9 | 16 Sept. | mtg-2p | 2.4 | 191 | NW5 | |
| 10 | 16 Sept. | 5p-7p | 166.8 | 208 | NW3 | |
| 11 | 17 Sept. | 11a-1p | 246.0 | 333 | NW3 | |
| 12 | 17 Sept. | 4p-6p | 62.4 | 333 | SW3 | 100:0 |
| 13 | 18 Sept. | 8a-10a | 156.0 | 185 | WNW1 | |
| 14 | 18 Sept. | 11a-1p | 309.0 | 130 | NNW1 | |
| 15 | 18 Sept. | 3p-5p | 226.8 | 46 | NNE2 | 97:3 |
| 16 | 19 Sept. | 7a-9a | 178.8 | 37 | E3 | |
| 17 | 21 Sept. | 0p-2p | 35.5 | 63 | SSE1 | 100:0 |
| 18 | 21 Sept. | 8p-10p | 75.6 | 63 | SE1 | |

also viel geringere sein, oder *vice versa*. Die Ursache hierfür mögen die ablandigen Winde sein, welche zumeist an der Ostküste wehten, im Gegensatz zu den Seewinden an der Westküste.

Andererseits will ich nicht vergessen, darauf hinzuweisen, dass der Atlantische Ozean, als ein Binnenozean, vielleicht überhaupt höhere Werte der induzierten Aktivität aufweist, als der "wirkliche" Ozean, der Pazifik.

Stade[2] fand auf einer Reise zwischen Deutschland und Brasilien ganz ausserordentlich hohe, zwischen 77 und 418 schwankende *A*-Werte.[3]

Andererseits muss man mit dem Begriff ablandiger oder ozeaner Winde schon in geringer Entfernung von der Küste sehr vorsichtig sein; wir bezeichnen die Winde einfach nach der Wind-

[2] *Meteorologische Zeitschrift*, 1910, S. 469.

[3] Auch Herr Dr. J. Laub scheint nach mündlicher Mitteilung auf einer Fahrt von Buenos Aires nach der Westküste Resultate im gleichen Sinne wie ich erhalten zu haben.

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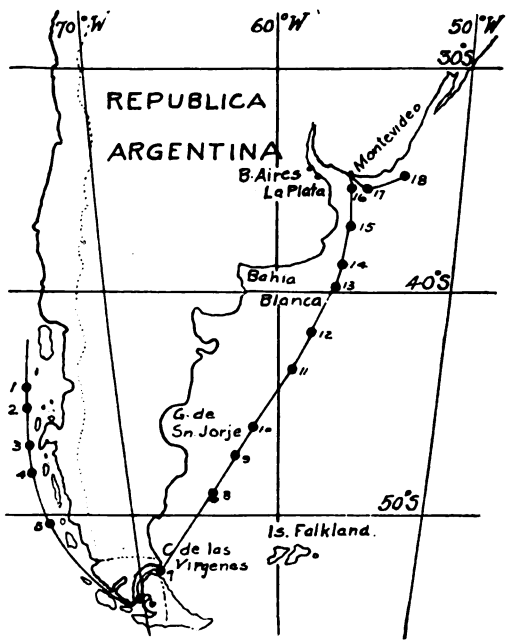
richtung, im stillen voraussetzend, dass die bewegte Luftmasse im ersten Falle von Land, im zweiten von See kommt. Wäre die Aktivität an den resp. Herkunftsorten nicht so verschieden und obendrein dem Zerfall ausgesetzt, so hätten wir in ihr eine äusserst feine Reagens für die Herkunft der Luftmassen, eine vortreffliche Unterstützung zur Lösung thermodynamischer Fragen. Trotzdem die Aktivität von diesen idealen Forderungen weit entfernt ist,




wird sie gelegentlich ein kleines Indiz für den Ursprung der Luft auf dem Meere, besonders in Küstennähe sein. Es ist so kein Zweifel, dass, mit Ausnahme wahrscheinlich des ersten Wertes, alle übrigen Westküstenwerte, deren höchster 244.8 ist, trotz reinen Seewindes, nicht gar zu lange vorher als Emanation mit dem Festlande, und zwar südamerikanischem, in Kontakt waren, oder ihm entstammen. Der kleine Ostküstenwert 2.4 in 191 km Entfernung scheint hingegen ozean zu sein trotz Luftbewegung vom Lande her; jedoch ist dieser Schluss viel weniger berechtigt als der frühere, da ja auch auf dem Lande ausserordentlich geringe Aktivitäten möglich sind. Auffallend ist der hohe Wert 246 in der grossen Küstenentfernung 333 km bei NW3. Angenommen die Emanation hätte



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den Wert bei gleicher Windstärke in der kürzesten Entfernung von der Küste aus zurückgelegt, so würde der Wert 246 rund 80% des Wertes von dem ursprünglichen an der Küste darstellen, aber selbst wenn diese Prozentzahl eine geringere wäre, so erhalten wir für das ursprüngliche $A$ durchaus wahrscheinliche Werte. Interessant ist, dass verschiedentlich Spuren von Th-Induktion nachgewiesen wurden; wenig auffallend ist dies bei der Messung in der landumgebenen Magellanesstrasse, auffallender, wenn auch nicht besonders erstaunlich bei der Beobachtung an Ort 15. Vier weitere Analysen ergaben nicht die geringsten Spuren an Thorium-Induktion.

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## BIOGRAPHICAL SKETCH OF JOHANN BAPTIST MESSERSCHMITT.

Johann Baptist Messerschmitt was born December 9, 1861, of well-to-do parents in the Bavarian town of Bamberg. He died April 13, 1912, after a life of unusual activity, in which his devotion to the chosen work, his great executive ability, and valuable scientific publications gave him an honored place in the scientific world.

His early education began at the Latin school in Bamberg, from which he went to the Realgymnasium in Würzburg, and later to the Technical High School in Zürich, and finally to Leipzig. Already enthusiastic in the study of science, and more particularly of astronomy, he accepted a position, without salary, in the Astrophysical Observatory at Potsdam, where he began his scientific labors under the late Prof. H. C. Vogel.

In 1887 he occupied a similar position at the University of Erlangen. In need, however, of a properly paid position, he entered the service of the Swiss Government as engineer of the Swiss Geodetic Commission for International Land Surveys. From 1888 to 1899 he covered a large part of Switzerland with astronomical and geodetic observations and measurements, especially with gravity determinations. During a part of this time he was also privat docent at the University and at the Technical High School of Zürich, besides publishing many scientific works. Desirous, however, of returning to his native land, he accepted in 1899 a position on the scientific staff of the Deutsche Seewarte at Hamburg in spite of the lower salary. His work consisted of magnetic observations and standardization of marine instruments.

It was not until 1903 that he finally was able to devote himself entirely to his chosen field. As observer, and later as director, of the Magnetic Observatory in Munich his scientific and executive abilities had full scope. The Observatory was still in its period of foundation and needed a person of marked organizing power. Within a remarkably short time the task was accomplished of completing the instrumental outfit, of arranging the observational work and of bringing a vast amount of observational material up to date and of publishing the results. He continued up to the time of his death in charge of this Observatory. The work was broadened under his direction so as to include seismic and atmospheric-electric observations, the Observatory becoming in time a geophysical branch of the Munich Astronomical Observatory. To Messerschmitt is due the careful magnetic survey of Bavaria and the organization of its seismological work.



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Not alone in the duties and observations of the positions occupied by Messerschmitt did his ability and energy show themselves. He belonged to many societies and organizations, in all of which he took a very active and prominent part, as treasurer, secretary, or as an active committee member. He is author of numerous publications, both scientific and popular. Whatever he undertook received his devoted care and unceasing enthusism.[1]

## PRINCIPAL MAGNETIC STORMS RECORDED AT THE CHELTENHAM MAGNETIC OBSERVATORY.

OCTOBER 1 TO DECEMBER 31, 1912.

*Latitude 38° 44'.0N; Longitude 76° 50'.5, or 5h 07m.4 W. of Greenwich.*

| GREENWICH MEAN TIME | | | | | | RANGE | | |
|---|---|---|---|---|---|---|---|---|
| Beginning | | | Ending | | | D (Declination) | H (Hor'l Int.) | Z (Vert'l Int.) |
| 1912 | | h | | | h | ′ | γ | γ |
| Oct. | 13, | 22 | Oct. | 15, | 7 | 22.6 | 93 | 50 |
| Nov. | 14, | 6 | Nov. | 14, | 23 | 23.5 | 71 | 22 |
| Dec. | 6, | 13 | Dec. | 7, | 18 | 21.4 | 76 | 30 |
| Dec. | 22, | 8 | Dec. | 23, | 22 | 15.4 | 76 | 25 |

GEORGE HARTNELL, *Observer-in-Charge.*

O. H. TITTMANN, *Superintendent,*
*Coast and Geodetic Survey.*

## *NOTES*

*1. Concerning observed and computed moments of inertia of magnets.* Referring to pp. 45-46 and 156-158, vol. 17, of this Journal, it may now be stated that, as the result of some recent careful weighings and measurements made by the Department of Terrestrial Magnetism using its strictly non-magnetic balance, the outstanding difference between the observed value of the moment of inertia of magnet H26 and the value, computed from the dimensions and mass, has been reduced to 1.1 parts in 1,000. The computed value is still, however, the higher one; the cause of the remaining difference is being further investigated.

*2. Office and Laboratory Building for the Department of Terrestrial Magnetism.* In addition to the appropriation for defraying the expenses

[1] This sketch prepared by Dr. H. M. W. Edmonds is based on Dr. C. W. Lutz's appreciation of the work of his former chief. (*Mit. d. Geog. Gesell., München, 7. Bl., 1912, 3. Hft.*

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of the current work and operations of this Department, the Trustees of the Carnegie Institution of Washington, at their annual meeting last December, set aside one hundred thousand dollars for purchase of a site and erection of a building for the Department. After an inspection of various sites, one embracing about seven acres, located in the District of Columbia, near Rock Creek Park, was finally found suited for the purpose and was accordingly purchased in April. The building will be about 52 x 101 feet and will consist of two stories and a basement. It will contain adequate facilities for office, laboratory work, and instrument shop, and will be ready for occupancy early in 1914.

*3. Homeward cruise of the Carnegie.* The magnetic survey yacht *Carnegie* left St. Helena on April 9th bound for Bahia, and is expected to return to her home port at the end of the year, thus completing the three years' circumnavigation cruise begun in 1910. On the trip from Coronel, Chile, to Port Stanley, Falkland Islands, made in December and January last, she encountered an exceptionally smooth passage in rounding the Horn. However, on her run from the Falkland Islands to St. Helena, February 22d to April 3d, 23 icebergs were sighted. The vessel is in command, as heretofore, of Mr. W. J. Peters. After leaving Bahia, she will touch once more at St. Helena, then proceed to Falmouth, where she is due in September. Thence the return to New York will be made probably via Porto Rico.

*4. Hudson Bay magnetic expedition. Dr. H. M. W. Edmonds*, of the Department of Terrestrial Magnetism, is at present in charge of an expedition to Hudson Bay designed to secure, from May to October, 1913, magnetic data in the region between the Albany and the Severn rivers. A special attempt will be made to locate, as accurately as possible, the focus of maximum total intensity in North America.

*5. Personalia.* We must record with regret the death of *Dr. Hermann Ebert*, since 1898 Professor of Experimental Physics at the "Technische Hochschule zu München." An account of his life and contributions to the topics of immediate interest to the readers of the Journal will be given in a future issue. *G. W. Walker* resigned early in the year as Superintendent of the Eskdalemuir Magnetic Observatory; the Observatory is at present in charge of *L. F. Richardson*. *L. A. Bauer* sailed from New York for Europe on April 22d, in order to arrange for co-operative magnetic work between the Department of Terrestrial Magnetism and certain foreign institutions. He will be gone about two months. *Dr. L. Geiger*, Göttingen, will take charge of the Samoa Geophysical Observatory for one year, beginning July 1, 1913, thus relieving *Prof. Angenheister*, who returns to Germany. *Prof. Arthur Schuster* was chosen Secretary of the Royal Society; he is also the President of the Physical Society.

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# ABSTRACTS AND REVIEWS

BRAGG, W. H. *Studies in Radioactivity.*[1]

In this book the author has given a brief resumé of what he regards as the principal features of that part of the subject of radioactivity which deals with the phenomena attending the passage of the $\alpha$, $\beta$, $\gamma$, and $X$ rays through matter. About the first half of the book consists of a discussion of the $\alpha$ and $\beta$ rays. The range, ionization curve, stopping power and scattering of each of the rays are considered, and the points of similarity and difference of the two kinds of rays brought out. The general properties of the $X$ and $\gamma$ rays are then briefly touched upon. Following this is a rather detailed discussion of the production of the secondary $\beta$ ray by $X$ and $\gamma$ rays, and at the end of this chapter the facts in regard to these phenomena are summarized. With these facts as a basis the author then sets forth arguments supporting the hypothesis that the $X$ and $\gamma$ rays are corpuscular in nature.

The author develops the subject in such a way as to show the strong family likeness which the three types of radiation bear to each other. "The $\alpha$ rays are positively charged, the $\beta$ rays negatively, the $X$ and $\gamma$ rays are uninfluenced by electric and magnetic fields. But, putting aside these differences and their immediate consequences, in their laws of penetration and scattering, in their actions on matter, and the reactions which they suffer themselves, the three forms of radiation differ in degree rather than kind. If it is assumed that the action of each form is direct and requires no assistance from any other form, it is difficult to believe at the same time that the $\alpha$ and $\beta$ radiations are corpuscular, and that the $X$ and $\gamma$ rays are spreading pulses in the ether. The distinction in form is too great: the $X$ and $\gamma$ rays have corpuscular properties also."

The summary in regard to the production of secondary $\beta$ rays from $X$ and $\gamma$ rays is as follows:

1. The speed of the $\beta$ rays due to the $\gamma$ or $X$ ray depends only on the quality or penetrating power of the exciting ray. The speed and penetration of the former increase with the penetration of the latter. The speed depends neither on the intensity of the $\gamma$ or $X$ ray stream, nor upon the nature of the atom in which the $\beta$ ray arises.

2. The initial direction of movement of the $\beta$ ray is more or less in continuation of that of the $\gamma$ or $X$ ray, this effect being most pronounced when the exciting ray is penetrating and the atomic weight small. In the case of hard $\gamma$ rays and light atoms the continuance is almost complete; in the case of soft $X$ rays and heavy atoms, it is very small.

It seems that the most powerful arguments supporting the view that the $X$ ray is corpuscular in nature are as follows: the velocity and penetrating power of the cathode rays giving rise to the $X$ rays are certainly not much greater than those of the secondary $\beta$ rays to which these $X$ rays in turn give rise; that the velocity and penetrating power of these secondary $\beta$ rays are independent of the distance of the source of the secondary $\beta$ ray from the source of the exciting $X$

[1] Macmillan & Co., London, 1912, pp. X + 193 22 cm.



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ray, and are independent of the nature of the matter in which the transformation takes place; that the direction of the secondary $\beta$ ray is more or less a continuation of that of the exciting $X$ ray. The author also discusses at some length experimental evidence which seems to show that $X$ and $\gamma$ rays do not produce ionization directly, but that the ionization which accompanies them is due to the $\beta$ radiation which they produce.

Having assumed that one $\beta$ ray supplies the energy for one $X$ ray, and that one $X$ ray supplies the energy for one $\beta$ ray, then since the energies of the primary and secondary $\beta$ rays are of the same order of magnitude, the author concludes that the energies of the $\beta$ ray, the $X$ ray, and the secondary $\beta$ ray are all nearly the same, and that little if any of the energy is lost in either of the transformations. It is then suggested that since on this view the energy of $X$ rays of various qualities is ascertainable, and since the energy of an $X$ ray completely defines it, the energy of the $X$ ray should be chosen as the definition of the quality of the $X$ ray instead of the absorption coefficient in aluminium as has been done heretofore. Although aluminium does not show any anomalies within the range of $X$ ray qualities usually considered, still there is little doubt that it would do so if the range included were wider.

The work of Sadler and Beatty has shown that the quality of the radiation produced by the secondary $X$ radiation from various metals varies with the nature of the radiator (the secondary $X$ ray radiator), the penetration increasing with the atomic weight of the radiator. The author therefore concludes that the energy of an $X$ corpuscle increases with the atomic weight of the atom of which it is characteristic.

Barkla's experiments have shown that the homogeneous radiation of any atom can excite the homogeneous radiation of an atom of less weight, but the converse does not occur. "In the language of the corpuscular theory, this means that one $X$ corpuscle may give rise to another $X$ corpuscle of less energy, but never of more; which is after all what we should expect."

Several special problems concerning the calculation of the ionization current in chambers through which $X$ and $\gamma$ rays are sent are discussed, and experimental data introduced to test the accuracy of the calculations. The form of the ionization curve to be expected from an ionization chamber filled with gas and traversed by $X$ or $\gamma$ rays is deduced and the various conditions which affect its validity are discussed.

The experiments of Madsen, Florence, the author, and others on the determination of the scattering of the $X$ and $\gamma$ rays are discussed, and the striking similarity between this phenomenon and the scattering of the $\beta$ rays is pointed out.

In the last chapter the author sets forth the arguments for and against the two theories as to the nature of the $X$ and $\gamma$ rays. He attempts to show that the ether pulse theory as it stands at present is quite incapable of accounting for the observed facts. In particular, it can not account satisfactorily for the phenomena of the scattering and the absorption of the $X$ rays, while the most fundamental relation between the $X$ ray and the electron, namely, their interchangeability, is quite incapable of explanation on this theory. On the other hand there are many facts that are difficult of explanation in terms of the neutral pair theory, namely, the polarization effects discovered by Barkla, and the fact that the $X$ rays move with the velocity of light.

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The author does not regard the neutral pair theory as at all complete, and having in mind the work of Einstein, Stark, and others, suggests that we ought to search for a possible scheme of greater comprehensiveness, under which the light wave and the corpuscular *X* ray may appear as the extreme presentments of some general effect. "If investigation from this point of view proves successful, we shall, I think, be guided and spurred on towards some great idea which will reconcile the old antagonism between the corpuscle and the wave."

*Aboard the "Carnegie," Oct. 4, 1912.* C. W. HEWLETT.

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DORNO, PHIL. C. *Studie Ueber Licht und Luft des Hochgebirges.*[1]

This book is an account of measurements made on the solar radiation and atmospheric electricity in Davos from December, 1908, to November, 1910, inclusive. The experiments were uninterrupted and have furnished a great deal of data which, besides being of the first importance to the physicist and the meteorologist, should prove of great value to physicians and physiologists in their studies relating to the "light cures" and "air cures" which are effected in the valley.

Davos, 46°48′ N. latitude and 9°49′ E. longitude, lies in a valley in the Alps 1,560 meters above sea level. The valley runs northeast and the mountains on either side are about 2,700 meters high. The width of the valley is about 1 km. and its length about 13 kms. It is closed at either end by mountains about 3,000 meters high. The valley is frequented by persons in a poor state of health who receive the so called "light" and "air" cures.

The work on atmospheric electricity falls under three heads: 1. Potential gradient; 2. Conductivity; 3. Vertical current. In addition, a few measurements were made on the dissipation factor with an Elster and Geitel apparatus with screening cylinder, on the conductivity with Gerdien's aspirator, on the ionization with Ebert's aspirator, and on the induced radioactivity. In the main body of the work Benndorf electrometers were used.

*Potential Gradient.* The potential gradient curve was measured up planimetrically for every hour and the average value of the potential gradient found. The average of all these hourly values for the day gave the value for the day. The results are grouped in three ways: 1. For all days; 2. for normal days; 3. for almost normal days. By "normal days" are meant days which were free from precipitation and almost cloudless. Even these almost cloudless days are not to be regarded as normal during föhn winds and during the winter calms when the vapor layers covering the valley at night remain longer than usual after the sun has risen. By the number of almost normal days is meant the entire number of hours free from precipitation divided by twenty-four. This group contains by far the greater part of the material. The results found for the normal and almost normal days were so very similar that the discussion is limited to the latter on account of the preponderance of the material which it contains.

As regards the *yearly variation of the potential gradient*, the maximum comes in January or February, while the minimum comes in June. The average yearly values for 1909 and 1910 were 55 and 64 volts per meter respectively. The amplitudes of the variations were about equal to the average value in each case. The yearly amplitude is thus about 100 per cent of the yearly average in Davos,

[1] Vieweg & Sohn, Braunschweig, 1911. Pp. VIII + 154; 78 tables and 33 figs.; 33½ cm.

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while in Potsdam it is only 57 per cent. The change from the summer to the winter value takes place very suddenly during November, while the change from winter to summer takes place more slowly during the months from March to June. The relation between the potential gradient and the covering of the ground with snow is very marked. In November, 1909, up to the 10th clear autumn weather reigned; during the 11th and 12th snow fell almost uninterruptedly, and on the 13th the sun shone on a glittering snow-covered landscape. The covering of snow remained from this day till spring. The mean of the daily values of the potential gradient from the 1st to the 10th of November was 51 volts per meter, from the 11th to the 30th its value was 81 volts per meter. In the spring the melting of the snow spreads over a much longer time, and not till June is the ground clear. The June minimum probably finds its explanation in this manner.

The chief characteristic of the daily variation of the potential gradient is the principal minimum, which occurs at about 4 A. M. throughout the year. There is also a secondary minimum occurring during the afternoon; it is most prominent during the months from March to November. The evening maximum from 7 to 8 P. M. is also very constant. The secondary minimum is so insignificant during the winter months that the variation may be regarded as one of a single period. A secondary maximum which is hardly noticeable in the winter months, travels with the time of the year from midday in winter to 7 A. M. in summer, slowly but regularly, and is equal to the evening maximum during the months from April to May and September to October. During the summer months this secondary maximum is much greater than the evening maximum. During the summer the daily curve is much flatter than during the winter. The amplitude of the daily variation lies between 70 per cent and 80 per cent of the average daily value for all seasons of the year, while in Potsdam the winter amplitude is 48 per cent and the summer amplitude 35 per cent.

The chief characteristics of the potential gradient in Davos are: 1. Small absolute values; 2. pronounced winter and summer type; 3. great yearly and daily amplitude; 4. great uniformity in the changes.

The main features in the daily variation are ascribed to the daily variations occurring in the vapor layers over the valley, whether the effects of these vapor layers are to be ascribed to humidity, dust, electric charges due to the accumulation of ions on their bounding surfaces, or to a radioactive property is yet to be shown, but it is certain that the appearance of the vapor layers increases the potential gradient whether the vapor layers come from above or below.

The direction of the wind has a characteristic influence on the value of the potential gradient. Wind from the northeast is accompanied by mean values and over; from the southeast by mean values and under. Bise wind is accompanied by high values of the potential gradient; föhn wind is accompanied by low values; the latter causing at times minus values.

During times of no precipitation, except for the last mentioned case of föhn wind, the potential gradient was always positive.

The disturbances of the normal potential gradient by precipitation are very marked. During quiet snowfall the daily mean is sometimes three times as great as usual, while rain produces the opposite effect.



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*Conductivity.* Both the + and — conductivity were found by Schering's method in absolute measure from the 1st of December, 1909, to the 30th of November, 1910. The results were grouped in two ways: 1. For all days; 2. for almost normal days. The results found are as follows: The absolute value of the conductivity found at Davos was very great, the yearly mean being three times as great as that observed in Potsdam. The order of magnitude of the conductivity is $10^{-4}$ E. S. U.

The *yearly variation* is very regular with its maximum, in June, and its minimum in January. The yearly amplitude is about 68 per cent, consequently not much greater than that at Potsdam (57 per cent), and smaller than that of the potential gradient.

The *daily variation* is very pronounced, and the form of its curve is a reflection in the base line of the form of the potential gradient curve, except in the afternoon hours the midday depression of the potential gradient has no analogy in the curve of the conductivity. The daily amplitude is about 115 per cent, while that at Potsdam is 27 per cent. This amplitude is also greater than the corresponding amplitude for the potential gradient.

The daily variation can be described as a variation with a single period with its maximum at 4 A. M. and its minimum at midday, disturbed by vapor layers, which increase the natural rate of fall of the curve in the forenoon and hinder the natural rate of rise in the afternoon.

The variations of $\lambda +$ and $\lambda -$ show great agreement on undisturbed days, and during this time $\frac{\lambda +}{\lambda -} = q$ is greater than in the daily mean. The value of $q$ varies within narrow limits and has for a yearly mean 1.13. The greatness of this difference in $\lambda +$ and $\lambda -$ the author thinks partly explainable by the experimental arrangement. The yearly variation of $q$ shows a maximum in winter and a minimum in summer; the daily variation shows a maximum at night and a minimum at day.

Except during precipitation, all the meteorological elements affect the potential gradient and the conductivity in the opposite senses.

It is shown that the conductivity of the air in a room takes on a characteristic change when the communications with the outside air are closed, so that the conductivity of the air can furnish a detector for fresh or used air.

*Vertical current.* The vertical current was calculated from the simultaneous values of the potential gradient and the conductivity for all normal days, and for the almost normal days. The results are as follows:

The + current is 1.13 times as great as the — current and their variations are parallel corresponding to the conductivities. The absolute values of the current are of the same order of magnitude as those found in other places, but somewhat smaller than in Potsdam. If correction be made for the altitude of Davos the two values are equal.

It is interesting to remember that the potential gradient was only one-third as great as at Potsdam, while the conductivity was three times as great. The two effects counterbalance, making the current the same. Its order of magnitude is $5 \times 10^{-7}$ E. S. U.

The *yearly variation* is very regular, with its maximum in February and its minimum in June. The yearly amplitude is small, about 37 per cent, the same as in Potsdam.

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The *daily variation* is astonishingly regular, with its maximum at night and its minimum at day. The mean daily amplitude was about 56 per cent, while that at Potsdam was only 15 per cent. The curves representing the daily variation for December and June are just opposite to one another. The same is true for the other pairs of months similarly separated from one another. The relation between solar radiation and the vertical current is very striking. The daily variation of the vertical current is just opposite to that of the solar radiation.

Summer is characterized by a small uniform current, winter and spring by great variations, autumn stands in between.

It was found that in the extreme, with equal current strengths, the electromotive force of the atmospheric electric current at sea level should be from 1 to 9 times as great as that in the mountains, and that the atmospheric electric vertical current of the mountains is similar to that at sea level in respect to current strength and yearly amplitude, but is different from it in respect to the quantity of energy and of daily amplitude.

Comparisons are made between the vertical atmospheric currents and those used in the electric baths and those tried in the electro-culture of plants.

The measurements of the dissipation factor, of the conductivity with the Gerdien aspirator, and of ionization with the Ebert aspirator were not very extended. Nothing was found which appeared to contradict results obtained at other places, or those given previously in this book.

A few measurements of the ionic velocities seem to show that these values are somewhat greater in Davos than at other places.

Measurements of the induced activity give values well in accord with those found at other places. The fourteen measurements made between the end of November, 1907, till the middle of May, 1908, gave values of $A$ between 33 and 165 (Elster and Geitel units). The highest values were found on clear days; light fog accompanied small values. The values of $A$ were smaller with föhn wind than with a north wind. The decay curve of the activity showed that the activity was due almost entirely to the disintegration products of radium. C. W. H.

*October 4, 1912.*

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BAUER, L. A. *Researches of the Department of Terrestrial Magnetism: Land magnetic observations, 1905-1910.*[1]

This publication contains the results of all magnetic observations made on land by the Department of Terrestrial Magnetism from the beginning of its observational work in February, 1905, to the end of 1910. Descriptions of the types of instruments used are given. The discussion of the general methods of the magnetic and astronomical field work includes, besides the general detail of selection and occupation of stations, specimens of field records, computations and determinations of constants and corrections. However carefully constructed, various instruments give results differing by small more or less constant amounts and hence arises the necessity of adopting some standard of reference. The Department has made for this purpose extensive intercomparisons of instruments at Washington, in the field, and at many magnetic observatories throughout the

[1] Carnegie Institution of Washington. Publication No. 175. Pp. iv + 186, with 10 plates 1912. 25 × 31 cm. Price unb. $3.

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world; with the data thus obtained it has been possible to reduce the magnetic results for the region covered in the publication to magnetic standards within an error in general in the order of the error of observation. The intercomparisons of the provisional magnetic standards adopted with the standards of twelve observatories in the northern hemisphere and four in the southern hemisphere are given, as also the indirect results of observations by other organizations at seven additional magnetic observatories in the northern hemisphere; these show that the provisional standards adopted are very close to international standards, at least so far as all practical requirements of a general magnetic survey of the Earth are concerned. The corrections to these standards for the various instruments used are given in detail. The results are summarized under the main geographical divisions as follows: Africa, 386 stations; Asia, 308 stations; Australia, 10 stations; Europe, 36 stations; North America, 328 stations; South America, 111 stations; Islands, Atlantic Ocean, 68 stations; Islands, Pacific Ocean, 51 stations. The total number of stations is 1,298; with reoccupations the total is 1,391. The Table of Results contains for each station the geographical latitude, longitude, date of observation, the observed values of magnetic declination, inclination, and horizontal intensity, the local mean times to the nearest one-tenth hour for each element, the instruments used, and the observer. Accounts of some of the expeditions are given with illustrations primarily to show in a general way the character of the field work and some of its difficulties. The last section of the volume is devoted to descriptions of stations arranged under the same geographical divisions adopted in the Table of Results.

J. A. FLEMING.

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## MAGNETIC VARIATION OBSERVATIONS OF THE GERMAN SOUTH POLAR EXPEDITION IN 1902-1903.[1]

The publication of the results of the German South Polar Expedition of 1901-1903 is continued in this volume, in which are reproduced the magnetograms secured between April, 1902, and January, 1903, at the place where the *Gauss* was held fast in the ice. It was at first intended to publish only a small number of typical curves, but on account of the unique location of the station and the fact that the preparation of the drawings for reproduction proved less troublesome than had been expected, it was decided to publish the whole series, and they are given for 236 nearly complete days.

On February 22, 1902, the *Gauss* became fast in the ice in south latitude 66° 02′ and east longitude 89° 38′ at a distance of about 85 km. from the nearest shore of Kaiser Wilhelm II Land, where the water was about 385 meters deep. As soon as it became apparent that the ship could not escape before the next summer, plans were made for securing a series of magnetic observations on the ice. A level place was selected about 450 meters from the ship, and two houses were built of ice, one for the absolute instruments and one for the variation instruments. The variation building was 3¼ by 5¼ meters inside, with a

[1] Bidlingmaier, F. Kurven-Sammlung von erdmagnetischen Variationen, beobachtet 1902-03 auf der Gauss-Station im südlichen Eismeer und mit einer geschichtlichen Einleitung, sowie ausführlichen Anmerkungen versehen, von Dr. Friedrich Bidlingmaier; mit dem Ad. Schmidt'schen Pantographen in einheitlichem Maszstab umgezeichnet, von Anton Bayer. Deutsche Südpolar-Expedition 1901-1903, herausgegeben von Erich von Drygalski; II Atlas. Erdmagnetismus. Berlin, Georg Reimer, 1912 (39 with 73 pl. and 9 figs.) 35 cm.

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passageway along one side and part of one end. The roof consisted of boards covered with linoleum and then with snow. The inner walls were covered with cork boards 20 cm. thick and the floor was covered with asbestos to keep out the light. The temperature conditions were very satisfactory in this room, the daily range being only about 0.3° C and the average temperature for three months being —5.5° as compared with about —15° outside. Here the variation instruments were mounted at the end of March and kept in operation until the first of July. Two recording apparatuses were provided, one for *D* and *H* and one for *Z*. Unfortunately one of the driving clocks broke down on March 27, and it was not until May 4 that the operation of the *Z* variometer began, a substitute recording apparatus having been improvised in the meantime. This substitute had a smaller drum and would run but 12 hours, so its operation entailed much additional labor and rendered the subsequent reproduction of the magnetograms more troublesome.

The weight of the houses and the snow which accumulated around them proved too great a load for the ice, and caused it to sink gradually, so that the instruments had to be releveled frequently. In the middle of May the water began to come into the instrument room, and by the end of June it was knee-deep. By that time a cave had been cut in the side of an iceberg nearby, and on July 2d the instruments were transferred to it. This cave was a room cut out of the solid ice, 10 m. long, 3 m. wide, and 2 m. high, reached by a passageway 11 m. long. The inner walls were covered with specially prepared canvas, but even then so much light came through in summer that one could see inside, though not enough to affect the photographic paper.

In this room the daily range of temperature was small and the seasonal change gradual. Up to November the routine work was carried on without especial difficulty, so that Dr. Bidlingmaier was able to take a four-weeks' sledge journey to the land and set up a second set of variation instruments with improvised recording apparatus, in order to see whether there was an appreciable difference between the variations on land and on the ice.

The iceberg proved disappointing as a support for variation instruments. It developed a slow, steady tilting toward the magnetic east, so that constant watching and frequent releveling was necessary to prevent loss of record. In a storm it shook enough to cause mechanical vibration of the magnets, and in summer great cracks ran through the ice field, affecting the orientation of the iceberg. During November and December the inside temperature was lower than outside, and there resulted frosting of the lenses and general icing up of the instruments. When the surface of the iceberg began to melt under the influence of the summer sun, the water began to trickle through numerous cracks into the instrument room. At first it froze until the floor surface had been raised half a foot. When the inside temperature got above freezing, the water collected on the walls and floor and had to be pumped out every day. In spite of these difficulties, the instruments were kept in continuous operation until January 30, 1903, when the nearest iceberg broke away and open water appeared within 900 meters of the station. This was taken as a warning to return the instruments to the ship, and on February 8th the *Gauss* succeeded in getting clear of the ice.

This brief outline will give an idea of the difficulties encountered in operating the variation instruments. In addition, the making of absolute observa-

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tions at a temperature of —10° to —20° was no easy task. Moreover, the observer often had to fight his way through a blinding storm in going from the ship to the variation house and back, depending for guidance upon a rope stretched along the way. Often the snow had to be shoveled away from the entrance to the instrument room before he could get in. The variation instruments were visited three times a day up to the end of June and four times a day after that date, the work being shared by Dr. Bidlingmaier and a young sailor named Lennart Reuterskjöld. One is filled with admiration for the courage, perseverance, and skill which they displayed in securing such a valuable series of observations in the face of such obstacles.

In making the drawings for reproduction, the pantograph devised by Dr. Adolf Schmidt was used. This instrument permits the reproduction of a curve with the ordinates and abscissas changed in a different ratio, with ample accuracy. There is little difficulty in following a curve with the tracing point, except where the movement is very small, or very large and abrupt. The work was done by Anton Bayer, who became very adept in a short time. The reproductions have a uniform time scale of 1 hour = 18 mm and scale values of 1 mm = 5$\gamma$ for $D$ and $H$ and 10$\gamma$ for $Z$. By suitable symbols, the time of occurrence and relative magnitude of an auroral display are indicated on the reproductions.

Details of the absolute observations, scale value determinations, etc., will appear in a later volume. The average values of the magnetic elements were approximately: $D = 62$ west; $H = 0.1330$; $I = 77°.2$.

*United States Coast and Geodetic Survey.* D. L. Hazard.

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## ATMOSPHERIC ELECTRIC OBSERVATIONS ON THE CHARCOT ANTARCTIC EXPEDITION, 1903-1905.[1]

During the sojourn in Graham's Land, latitude 65° 04′ S., longitude 65° 46′ W. (approximately at the intersection of the Antarctic Circle and the meridian passing through Cape Horn), a special investigation of atmospheric electricity was made. The aim of the research was to determine (1) the general nature of the curve of the diurnal variation of the electrical field of the atmosphere near the ground at this point, (2) the mean diurnal value of the electrical field, (3) the effects of the various meteorological elements upon the diurnal variation of the value of the field, and (4) the rate of dispersion of the electrical charge contained in a body suspended in the atmosphere and insulated from the earth. The observations extended from November 7 to December 24, 1904, inclusive.

The electrical instruments used were (1) a collector, consisting of a small particle of a radium salt mounted in an aluminium frame, (2) an insulator, in which successive enclosures of unfired porcelain, tile, wax, and paraffine were used, (3) an electroscope, and (4) a specially devised apparatus to measure dispersion.

It was impossible to make the electrical observations at the same hour each day. However, at intervals of 2 to 3 hours throughout the 24 hours of each day sets of 10 to 30 successive readings, separated by intervals of about 9 or 10

[1] Expédition Antarctique Française, 1903-1905, Commandée par le *Dr. Jean Charcot*. Électricité Atmosphérique, par *J. J. Rey*, Lieutenant de Vaisseau. Pp. 191-260.

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seconds, were made, and the average of each set was considered as one observation. A total of 506 sets of readings were obtained. The sign of the field was determined by means of the effects produced by a charged ebonite rod as it was brought near the electroscope.

The results and conclusions are as follows:

(1) *Diurnal variation of the electrical field.* When all observations were combined, regardless of meteorological conditions (type *M*), the results show that the curve representing the diurnal variation of the electrical field is a simple one, consisting of a single wave with a sharp minimum about 4 A. M. and a marked maximum about 2 P. M.

(2) *Mean diurnal value of the electrical field.* The average minimum value of the field is about 50.5 volts; the average maximum value about 118.3 volts; the average value about 69.1 volts. The mean amplitude of oscillation is about 67.8 volts, and is practically equal to the mean value of the field, the former being 98 per cent of the latter in value.

(3) *Relation to meteorological conditions.*

With clear sky (type *A*) the average value of the field falls to 62.4 volts; the minimum is much weaker than in type *M*, 18.2 volts, and it occurs earlier, 1 A. M.; the maximum is 108.1 volts (probably too large, as it is the result of but one day's observations).

With cloudy sky (type *B*) the 4 A. M. minimum tends to disappear, the field remaining unchanged during the early part of the day; the maximum, 97.7 volts, occurs about 4 P. M.; and a secondary minimum occurs between 9 P. M. and 10 P. M. With a cloudy sky the curve is more irregular than with a clear sky.

With strong northeast winds (type *C*) (relatively warm equatorial winds) the afternoon maximum reaches 211.6 volts, while the morning minimum falls to 11.2 volts, the range being 200.4 volts, and the average value of the field 77.2 volts. With these winds, therefore, the maximum and minimum are greatly exaggerated, though the mean value of the field is but a few volts higher than that of type *M*. These observations, as well as those obtained by investigators in other places, show that there is a marked relation between the direction of strong winds and the diurnal range in the value of the field.

With moderate northeast winds (type *D*) (velocity not over 14 m. p. h.), and with moderate winds from any other quarter (type *E*), the results are identical—a diurnal average value of 71 to 72 volts with a maximum of 108 to 115 volts at 2 P. M. There is no observation for type *D* during the early hours of the day. Type *E* gives a minimum of 54.0 volts at 5 A. M.

With calms or with weak winds (type *F*) the electrical conditions are similar to those prevailing with a clear sky (type *A*). The average diurnal value of the field is 64.6 volts, and the maximum, 111.4 volts, occurs at 2 P. M., while the minimum occurs about midnight.

With fog (type *G*) the mean diurnal value of the field is 130.5 volts, about double the average for all conditions (type *M*). The sudden increase in the value of the field at the moment of a fog invasion is very marked. With condensation the value of the field falls below 35 volts; sometimes it appears to become negative, but this can not be stated with certainty.

With snow (type *H*) the average value of the field is 62.3 volts. Some snowfalls have given very strong fields, over 300 volts, which could not be measured

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by means of the electroscope used. On the other hand, some snowfalls gave very weak or no fields. Sometimes the field was strong at the beginning of snow precipitation, then it became suddenly weak or even vanished while the snow was still falling. In no case has a snowfall given strong negative fields.

A normal average value of the field (type *N*) was determined after eliminating all abnormal values—those under 35 or over 150 volts. The characteristics of this curve are (*a*) minimum value, 50.5 volts, at 4 A. M., (*b*) maximum value, 94.6 volts, at 2 P. M., (*c*) diurnal average, 68.4 volts, (*d*) amplitude of diurnal oscillation, 44.1 volts, and (*e*) relation of amplitude to mean value, 0.64.

The curve of the diurnal variation in the value of the field in summer on Graham's Land was found to be a single wave, and similar to that derived by M. A. Paulsen during the winter of 1899-1900 at a height of 1,200 meters in a lower latitude. At high altitudes in temperate regions the diurnal curve consists of two waves, like the well-known curve of barometric pressure. Various observations made in intermediate latitudes by means of balloons show that the value of the field decreases up to a height of 3,000 meters, and remains constant beyond that level.

For all places where the diurnal curve of the value of the field is a single wave, the maximum occurs in the warmer part of the day and the minimum during the colder part. Moreover, it is well established everywhere in the northern hemisphere that the value of the field is greater in winter than in summer. From these facts it is apparent that the change of the air temperature is not a direct cause of the change in its electrical state. Though the diurnal curve of humidity is a single wave, it is sometimes parallel to and sometimes the inverse of the potential curve. The barometric minimum occurring at midnight is notably before that of the potential minimum; the barometric and potential maxima are coincident in time.

It is now well established that the annual variation in the value of the electrical field is related *not* to the season of the hemisphere, *but rather* to the position of the Earth on the ecliptic. The electrical field of the atmosphere is stronger for the whole of the Earth when the latter is in perihelion, and is weaker when it is in aphelion; it is not necessarily true that the field is strong in the northern hemisphere when it is weak in the southern hemisphere, and vice versa. This idea agrees with modern theories concerning phenomena which have causes outside the planet, and the effects are related to solar emissions of electric waves and of electric corpuscles, and to the immediate action of the Sun on meteorological and magnetic phenomena of the Earth.

(4) *Dispersion.* No marked difference between the speeds of dispersion of positive and of negative charges was found, probably owing to the remarkable richness of ions in the air of polar regions. At high elevations in temperate latitudes there is a marked difference between the two rates of dispersion. While the meteorological conditions there are similar to those near sea-level in Graham's Land, the nature of electrical dispersion appears to be different, as far as positive and negative charges are concerned.

The proportion of the electrical load lost by dispersion during 1 minute of time was found to be 0.0309. Unlike the results obtained elsewhere, the *proportion* of the load lost during successive minutes changes, while the *actual voltage* lost seems to remain constant from minute to minute. Moreover, the higher the value of the electrical field of the atmosphere the slower appears to be the rate of dispersion. ANDREW H. PALMER.

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## RADLER DE AQUINO'S NEWEST NAVIGATION ALTITUDE AND AZIMUTH TABLES.[1]

The fact that this latest book by Lieut. Radler de Aquino, of the Brazilian Navy, offers ready solutions, without the use of logarithms, for nearly all the problems of navigation, that the method used is general for all solutions, and that it contains in compact form all the necessary tables, should make it popular, and especially so to the navigator who dislikes to use logarithms.

After the tables are once thoroughly understood and the various precepts remembered, they can be used very readily, being particularly valuable for star sights, when two or more stars are observed simultaneously, for star identification, and for obtaining corrections for variations in data.

The addition of a plane traverse table and of the various correction tables common to navigation, is to be commended, making the book more nearly a universal solver for the navigator. The more open and extensive traverse table of the "American Practical Navigator" may be preferred by some as more convenient. However, the more extensive tables contemplated by the author will add much to the speed and accuracy of the method.

J. P. Ault.

[1] Aquino, Radler de. The "newest" navigation altitude and aximuth tables for facilitating the determination of lines of position and geographical position at sea. The simplest and readiest in solution. Plane and spherical traverse tables for solving all problems of navigation. Second stereotyped edition. Enlarged and improved. London, J. D. Potter; Rio de Janeiro, D. Norris, 1912 (xlix + 176 + 12). 25 cm. New log and versine altitude tables. (Reprinted from the author's "The 'newest' navigation altitude and azimuth tables," 2d edition, 1912). London, J. D. Potter; Rio de Janeiro, D. Norris, 1912 (circa 40 + 11). 25 cm.

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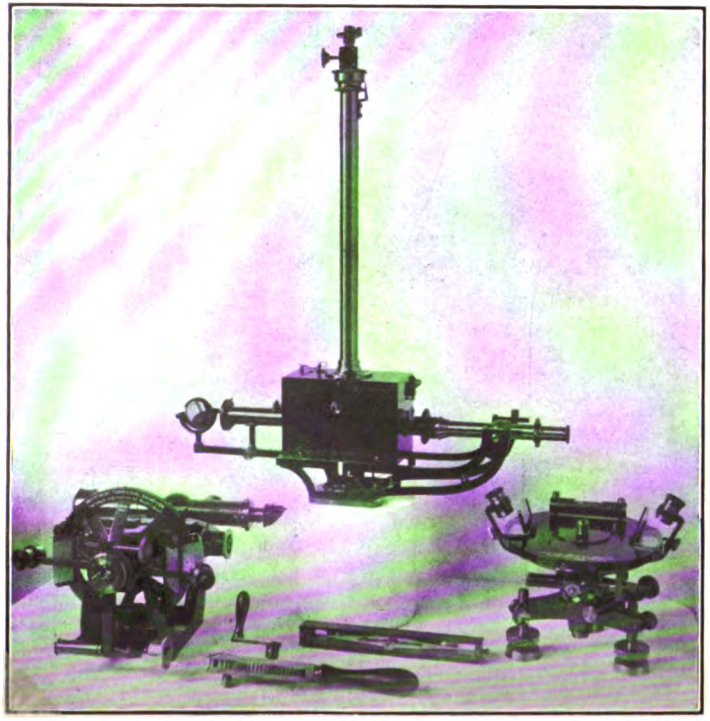

Fig. 1. Base, magnetometer attachment, and earth-inductor attachment.

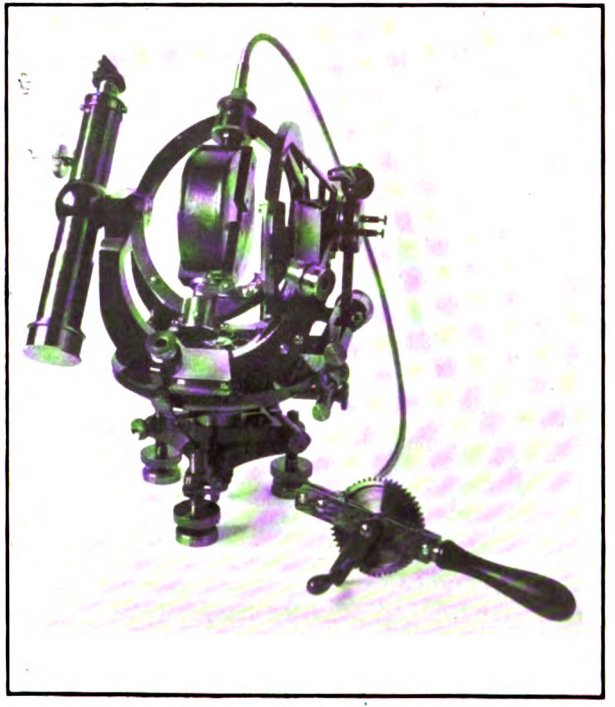

Fig. 2. Earth inductor with flexible shaft attached.



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*Terrestrial Magnetism*
*and*
*Atmospheric Electricity*

VOLUME XVIII SEPTEMBER, 1913 NUMBER 3

# DESCRIPTION OF THE C. I. W. COMBINED MAGNETOMETER AND EARTH INDUCTOR.

BY J. A. FLEMING AND J. A. WIDMER.

Owing to the difficulties generally experienced in the satisfactory determination of the corrections of dip needles to standard and the possible changes in these corrections with geographical variation in magnetic intensity and inclination and with wear of pivots of the needle, it was found desirable to further improve the universal magnetometer[1] of the Department of Terrestrial Magnetism by replacing the dipping needle by an earth inductor attachment. The comparisons made with earth inductors by the observers of the Department in various regions of the globe have been far more satisfactory than the dip circle comparisons.[2] In accordance, therefore, with the Director's instructions, the present instrument has been designed and constructed in the shop of the Department. The instrument consists essentially of four parts: (*a*) the base, (*b*) the magnetometer attachment, (*c*) the earth inductor and theodolite attachment, and (*d*) the galvanometer. The effort has been to secure a compact, portable instrument, with a minimum number of loose accessories, for rapid field work of high precision.

The *base* (see Fig. 1, Pl. IV) is of the usual double-center type. The horizontal circle is 102 mm. in diameter, with graduations at thirty-minute intervals and with two verniers, the least count of each vernier being one minute of arc; the graduation is

[1] FLEMING, J. A. Two new types of magnetometers made by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, *Terr. Mag.*, v. 16, 1911 (1-9).

[2] *Cf.* FLEMING, J. A., Comparisons of magnetic observatory standards by the Carnegie Institution of Washington. *Terr. Mag.*, v. 16, 1911 (61-84, 137-162).



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such, however, that estimations to one-quarter minute of arc can be readily and definitely made. The base is supported by three-foot screws.

The *magnetometer attachment* (see Fig. 1, Pl. IV), including magnet system and suspension, is similar to that described in the Journal of *Terrestrial Magnetism* for March, 1911. A small improvement over the type there described has been made by the elimination of the hood connection between the magnetometer-telescope and the magnet-house. The hood has been replaced by an attachment with concave, plush-lined, spherical surface attached to the magnet-house, and against which an adjustable cap with corresponding convex spherical surface mounted at the object end of the magnotemeter telescope is in contact when the telescope is horizontal. This permits free vertical motion of the telescope when making sightings on marks slightly elevated or depressed and, at the same time, serves effectually to keep any currents of air out of the magnet-house. The magnetometer attachment, including its telescope and suspension, is packed assembled and may be mounted on the base in one operation by a device similar to that described in the article cited above.

The *earth inductor and theodolite attachment* (see Fig. 1, Pl. IV) consists of a *U*-shaped standard frame supporting an inner ring in which are provided agate bearings to carry the inductor coil; the telescope and vertical circle are mounted on the axle ends of this ring outside of the standards. The center of the telescope is 78 mm. from the center of the instrument. The telescope has a magnifying power of about seventeen. Suitable shade glass and prismatic eyepiece are provided for astronomical observations. The reticle is a small cross of two fine fibers at right angles. The vertical circle is 102 mm. in diameter and has the same style of graduation as the horizontal circle, being read directly to one minute of arc by two verniers and by estimation to one-quarter minute. The circle is attached to the axle of the bearing ring in such a way that the relation of the line of sight of the telescope to the zero graduation of the vertical circle is constant, and the vertical circle rotates with the telescope. The two verniers are fixed in position by suitable frame work attached to the standards of the instrument. The graduated circle is protected by a sheath of brass with uncovered openings at the verniers. To protect the circle and verniers against tarnishing, they are coated with lacquer.

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The ring carrying the bearings for the coil is oval-shaped, the inner smaller diameter being 80 mm. and the inner greater diameter about 103 mm. The section of this ring is about 8 mm. by 10 mm., with suitable lugs cast on at the points where the axle supports and coil bearings are placed. The bearings for the rotation axis of the coil are of agate, the bearing surfaces being cone-shaped. The bearing at the commutator end is the smaller; the one at the opposite side is larger, to permit the drilling along the center axis of a hole of sufficient diameter (4 mm.) to permit of making attachments for the pin connection for the flexible shaft used for rotating the coil. The cap carrying the agate bearing at the commutator end is provided with adjustments for careful centering, while that carrying the opposite bearing has a longitudinal adjustment along the axis to permit the taking up of any slight wear or lost motion in the bearings.

The coil is mounted on a hard rubber spool 24 mm. thick; the inner diameter of the spool is 26 mm. and the outer 74 mm. The winding consists of 0.23 kilogram of double-wound silk magnet wire, Brown and Sharpe gauge No. 28, in 49 layers and 2062 turns; at every third layer of wire there is a double layer of paper; the width of the winding is 18 mm. and the outer diameter 71 mm. The coil is covered with a heavy coating of paraffin to protect it against possible abrasion and short-circuiting of the turns and against moisture. The ends of the phosphor-bronze rotation axis for the coil spool are attached to the hard rubber by means of two *U*-shaped brass straps. The commutator is mounted on a core of fiber. The brushes are of hard copper attached to the brass supporting-ring by screws, and insulated from it by hard rubber sleeves and washers, and connected to insulated wires running in grooves in the ring and terminating at the binding posts (Fig. 2, Pl. IV) at the extremity of the axle on the verticle circle side of the instrument. Suitable means for clamping the vertical circle and for slow motion are provided. For the purpose of facilitating more rapid approximations, a micrometer head (see Fig. 2, Pl. IV) has been attached to the slow motion screw and a suitable index provided; motion through three divisions on this head corresponds approximately to one minute of arc on the vertical circle.

The magnetic meridian may be determined by direct and reverse sightings with the telescope on a mark of known magnetic azimuth. As this method, however, is not always feasible, a compass (see Fig. 1, Pl. IV) has been provided for determining the

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magnetic meridian. Mounting for the compass is provided on the ring supporting the inductor coil, the ring being placed in a horizontal position by setting the vertical circle vernier zeros at 0° and 180°. The needle, 120 mm. long, is mounted in a brass case with index mirrors at the north and south ends, and readings effected by shifting the instrument until the needle point and its reflection in the mirror are in the same vertical plane with the index line on the mirror surface. A balancing weight is mounted on a long screw. The needle may be balanced by removing the end cap provided with a brass knob after removing the three screws holding the cap in place; the glass cover-plate is then drawn out, the needle taken from the tube, and the balance weight screwed in or out, as may be necessary. In replacing the needle, it is first replaced on the pivot, and the cover glass and cap are then mounted.

The coil is rotated by means of a flexible shaft consisting of two closely-wound spirals of phosphor-bronze wire operated by two gears attached to a crank handle, as shown in Fig. 2, Pl. IV.

The *galvanometer*, as shown on Pl. V, is of the Kelvin type. The spindle center for this instrument is mounted in a hard rubber base 100 mm. in diameter and 12 mm. thick, which in turn is supported by three leveling foot screws insulated from the center by the rubber base. The four coils are each wound with 80 grams of double silk-wound magnet wire, Brown and Sharpe gauge No. 34; there are 1880 turns in each coil. The outside diameter of the winding of each coil is about 30 mm., the inside 4 mm., and the thickness about 9 mm. They are so arranged that they may be easily connected either in series or multiple. The terminals are each lettered, and for series connection binding-post connections are to be made in the order of the alphabet, namely, *A*, *B*, *C*, *D*, *E*, *F*, *G*, and *H*. The connections from the earth inductor are made at *A* and *H*. Each pair of coils is mounted on a hinged frame (see Fig. 2, Pl. V), so that the galvanometer-house may be easily opened and new suspension inserted or other repairs made, as may be necessary. The spools of the coils are carefully insulated from the brass parts of the instrument by the use of hard rubber.

The magnet system, consisting of six magnets (Fig. 2, Pl. V), is mounted in two groups of three by means of sealing wax in two light brass frames supported by a phosphor-bronze wire. In order that the system would be as closely as possible astatic, the magnets are very carefully made and magnetized in accordance with the methods already outlined in the article above referred to

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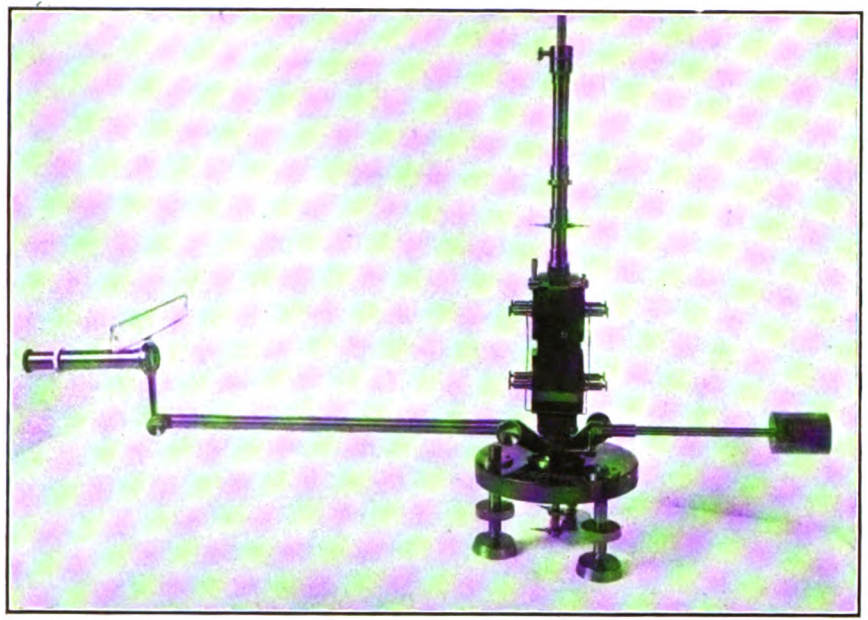

Fig. 1. View of galvanometer, with reading telescope.

Fig. 2. Detail view of galvanometer.

C. I. W. COMBINED MAGNETOMETER AND EARTH INDUCTOR.

[PLATE V.]

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in the manufacture of magnetometer-magnets. The six magnets used for the galvanometer system consist of two 8 mm. long and 0.8 mm. in diameter, and four 6.4 mm. long and 0.8 mm. in diameter. The sheet-brass pieces which carry the magnets are 0.15 mm. thick, and each stamped with grooves to support the magnets. The phosphor-bronze wire supporting the damping vane, mirror, and magnet systems is 0.6 mm. in diameter. The air-damping vane of sheet brass is 0.05 mm. thick, 8 mm. wide, and 20 mm. long, and mounted at center of system. The mirror, as will be seen from Fig. 2, Pl. V, is attached directly to the light brass damping vane by tongues stamped from the vane itself. The air damping is effected by means of the brass vane and a rectangular box provided between the coils; in the half of this box mounted on the one coil frame there has been mounted at the center a *V*-shaped piece to increase the efficiency of the air damping. Attachments for control magnets (see Fig. 1, Pl. V) are provided on the suspension tube and on a support mounted below the hard rubber bearing plate. These arrangements are friction-tight, so that the control magnets may be adjusted as desired either vertically or in azimuth. The control magnets are made very small, and it has been found that in case all are used no effect is produced on the inclination when the galvanometer is mounted at a distance of one meter from the inductor. At Washington, D. C., it has not been found necessary to make use of the control magnets when the coils are connected in series. The suspension is of very fine cocoon fiber, about 0.006 mm. diameter. The fiber is attached to a rod mounted in a ring, in which it may be clamped by means of a set screw, and the height so adjusted. This ring in turn rests upon a second ring permanently attached to the suspension tube, on which there is a second clamping screw, which serves to permit turning the suspension and removing torsion of the fiber. The entire length of the suspension from the point of attachment to the magnet system is about 120 mm. A special clamp has been provided for clamping the magnet system in place when the instrument is being transported or when not in use. This is shown in Fig. 2, Pl. V; it consists of one fixed arm with a *V*-cut surface to receive the brass wire of the suspension, and a second movable arm with corresponding *V*-surface at its end, held in place by a spring operated through a milled nut on the outside of the instrument. When this nut is loosened the spring forces the movable arm against the fixed arm, clamping the suspension. The clamping surfaces in contact are

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sufficiently long to insure no deformation of the suspension system.

A plano-parallel glass window has been provided in the damping box on one side of the instrument, so that readings may be made by means of a telescope and scale. The telescope and scale, with counter weight and arms carrying the same (see Fig. 1, Pl. V), are mounted on a ring outside the spindle bearing of the instrument, and may be placed in any azimuth independent of the position of the house of the galvanometer; a suitable lever-clamp is provided, so that the arms may be clamped in any position. The arms carrying the counter weight and telescope and scale are so arranged that they may be folded against the instrument for transportation; the reading telescope, however, must be unscrewed from its mounting when packing the instrument in its case. The telescope is supplied with a simple reticle of two fibers at right angles. The distance between the object lens of the telescope and mirror is about 25 cm. The scale is on white xylonite, and is 10 cm. long, with graduations at every millimeter; it is mounted somewhat above the horizontal line through the center of the mirror, while the telescope is mounted a corresponding distance below this line. The relations of the scale, telescope, and mirror always being fixed, it is not difficult to find the reflection of the scale, so that the instrument may be quickly set up and adjusted for field use.

The galvanometer is supplied with an independent tripod, and is clamped in place on this tripod with notches fitting into corresponding grooves in the three foot screws.

The instrument case for the entire instrument is made of mahogany, the inside dimensions being 36 cm. wide by 51 cm. long by 14 cm. deep, the material being 1.6 cm. thick. All parts of the instrument, including accessories, the two tripod heads, and the deflection bar are packed in this instrument case, the total weight of which, with the instrument and its accessories, is 15.3 kilograms. The net weight of the instrument, with its appurtenances, but not including the two tripod heads, is 7.2 kilograms; the two tripod heads weigh 1.1 kilograms, and the instrument box 7 kilograms. The tripod legs for the two tripods are carried separately in a canvas carrying case, the total weight of the tripod legs and case being 6.8 kilograms.

Carnegie Institution of Washington,
Department of Terrestrial Magnetism,
*Washington, D. C., July 1, 1913.*

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# MAGNETIC DECLINATIONS AND CHART CORRECTIONS OBTAINED BY THE *CARNEGIE* FROM PORT STANLEY, FALKLAND ISLANDS, TO ST. HELENA AND BAHIA, FEBRUARY TO APRIL, 1913.[1]

By L. A. Bauer and W. J. Peters.

(*Minus sign indicates west declination, and plus, east declination.*)

## A. Port Stanley to St. Helena.

| Date | Position | | Carnegie | Chart Values | | | Chart Corrections | | |
|---|---|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | Brit. | Ger. | U. S. | Brit. | Ger. | U. S. |
| 1913 | ° ′ | ° ′ | ° | ° | ° | ° | ° | ° | ° |
| Feb. 22 | 51 35S | 57 05W | + 9.7 | + 9.6 | +10.0 | + 9.7 | +0.1 | —0.3 | 0.0 |
| 27 | 52 16S | 36 00W | — 4.3 | — 5.3 | — 4.6 | — 5.8 | +1.0 | +0.3 | +1.5 |
| 27 | 52 10S | 34 22W | — 6.2 | — 6.5 | — 5.7 | — 6.9 | +0.3 | —0.5 | +0.7 |
| Mar. 3 | 50 45S | 25 08W | —12.9 | —13.4 | —12.8 | —12.9 | +0.5 | —0.1 | 0.0 |
| 7 | 49 15S | 14 48W | —19.9 | —20.3 | —19.4 | —19.2 | +0.4 | —0.5 | —0.7 |
| 8 | 49 42S | 13 04W | —20.7 | —20.9 | —20.1 | —20.1 | +0.2 | —0.6 | —0.6 |
| 10 | 48 38S | 8 55W | —23.2 | —23.2 | —22.7 | —23.0 | 0.0 | —0.5 | —0.2 |
| 11 | 47 53S | 5 50W | —24.5 | —24.8 | —24.6 | —24.8 | +0.3 | +0.1 | +0.3 |
| 12 | 47 12S | 2 55W | —25.6 | —25.9 | —26.0 | —26.6 | +0.3 | +0.4 | +1.0 |
| 13 | 46 58S | 0 24W | —26.5 | —26.9 | —27.3 | —27.8 | +0.4 | +0.8 | +1.3 |
| 14 | 46 12S | 1 46 E | —27.4 | —28.1 | —28.3 | —28.7 | +0.7 | +0.9 | +1.3 |
| 16 | 41 23S | 5 46 E | —29.0 | —30.4 | —30.0 | —30.1 | +1.4 | +1.0 | +1.1 |
| 17 | 40 04S | 7 27 E | —29.3 | —30.8 | —30.3 | —30.5 | +1.5 | +1.0 | +1.2 |
| 18 | 38 42S | 7 34 E | —29.4 | —30.7 | —30.2 | —30.4 | +1.3 | +0.8 | +1.0 |
| 19 | 37 46S | 7 51 E | —29.4 | —30.4 | —30.1 | —30.3 | +1.0 | +0.7 | +0.9 |
| 22 | 34 35S | 7 12 E | —28.8 | —29.7 | —29.7 | —29.6 | +0.9 | +0.9 | +0.8 |
| 24 | 32 45S | 7 58 E | —28.3 | —29.0 | —29.2 | —28.8 | +0.7 | +0.9 | +0.5 |
| 24 | 31 40S | 8 26 E | —28.2 | —28.4 | —28.7 | —28.4 | +0.2 | +0.5 | +0.2 |
| 25 | 29 08S | 7 20 E | —27.8 | —27.7 | —28.0 | —27.5 | —0.1 | +0.2 | —0.3 |
| 26 | 27 36S | 6 45 E | —27.2 | —27.2 | —27.3 | —27.0 | 0.0 | +0.1 | —0.2 |
| 27 | 25 15S | 5 59 E | —27.5 | —26.4 | —26.5 | —26.0 | —1.1 | —1.0 | —1.5 |
| 27 | 24 29S | 5 44 E | —26.6 | —26.2 | —26.2 | —25.8 | —0.4 | —0.4 | —0.8 |
| 28 | 22 22S | 5 12 E | —26.4 | —25.5 | —25.4 | —25.0 | —0.9 | —1.0 | —1.4 |
| 29 | 20 04S | 4 46 E | —24.5 | —24.4 | —24.4 | —24.0 | —0.1 | —0.1 | —0.5 |
| 30 | 19 11S | 2 20 E | —24.9 | —24.7 | —24.4 | —24.1 | —0.2 | —0.5 | —0.8 |
| 31 | 18 45S | 1 04 E | —24.8 | —24.9 | —24.5 | —24.1 | +0.1 | —0.3 | —0.7 |
| 31 | 18 23S | 0 01 E | —24.8 | —25.0 | —24.5 | —24.1 | +0.2 | —0.3 | —0.7 |
| Apr. 1 | 17 39S | 2 02W | —24.9 | —25.0 | —24.6 | —24.0 | +0.1 | —0.3 | —0.9 |
| 2 | 17 13S | 3 11W | —25.0 | —25.0 | —24.5 | —24.0 | 0.0 | —0.5 | —1.0 |
| 2 | 16 44S | 4 15W | —25.0 | —24.8 | —24.5 | —23.9 | —0.2 | —0.5 | —1.1 |
| 3 | 16 15S | 5 13W | —24.6 | —24.6 | —24.4 | —23.8 | 0.0 | —0.2 | —0.8 |

[1] For previous tables, see *Terr. Mag.*, v. 15, pp. 57-82, 129-144; v. 16, pp. 133-136; v. 17, pp. 31-32, 97-101, 141-144, 179-180; v. 18, pp. 63-64.



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## B. St. Helena to Bahia.

| Date | Position | | Carnegie | Chart Values | | | Chart Corrections | | |
|---|---|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | Brit. | Ger. | U. S. | Brit. | Ger. | U. S. |
| 1913 | ° ′ | ° ′ | ° | ° | ° | ° | ° | ° | ° |
| Apr. 10 | 15 42S | 7 05W | —24.7 | —24.5 | —24.4 | —23.8 | —0.2 | —0.3 | —0.9 |
| 10 | 15 28S | 8 31W | —24.7 | —24.4 | —24.5 | —23.8 | —0.3 | —0.2 | —0.9 |
| 11 | 15 08S | 10 22W | —24.4 | —24.2 | —24.5 | —23.7 | —0.2 | +0.1 | —0.7 |
| 11 | 14 53S | 11 52W | —24.5 | —24.0 | —24.4 | —23.5 | —0.5 | —0.1 | —1.0 |
| 12 | 14 36S | 13 34W | —24.8 | —23.7 | —24.3 | —23.4 | —1.1 | —0.5 | —1.4 |
| 13 | 14 08S | 16 25W | —23.6 | —23.2 | —23.9 | —23.1 | —0.4 | +0.3 | —0.5 |
| 13 | 13 54S | 17 41W | —23.5 | —23.0 | —23.7 | —22.9 | —0.5 | +0.2 | —0.6 |
| 14 | 13 37S | 19 09W | —23.0 | —22.7 | —23.4 | —22.7 | —0.3 | +0.4 | —0.3 |
| 14 | 13 25S | 20 29W | —22.7 | —22.5 | —23.0 | —22.5 | —0.2 | +0.3 | —0.2 |
| 15 | 13 12S | 21 45W | —22.4 | —22.2 | —22.7 | —22.2 | —0.2 | +0.3 | —0.2 |
| 15 | 13 05S | 22 49W | —22.0 | —22.0 | —22.4 | —22.0 | 0.0 | +0.4 | 0.0 |
| 16 | 12 49S | 23 54W | —21.3 | —21.6 | —22.1 | —21.7 | +0.3 | +0.8 | +0.4 |
| 16 | 12 41S | 24 49W | —21.4 | —21.3 | —21.7 | —21.4 | —0.1 | +0.3 | 0.0 |
| 17 | 12 44S | 25 55W | —20.9 | —21.0 | —21.4 | —21.2 | +0.1 | +0.5 | +0.3 |
| 17 | 12 45S | 26 55W | —20.4 | —20.5 | —21.0 | —20.8 | +0.1 | +0.6 | +0.4 |
| 18 | 12 49S | 28 08W | —20.0 | —20.0 | —20.2 | —20.2 | 0.0 | +0.2 | +0.2 |
| 18 | 12 47S | 29 25W | —19.5 | —19.4 | —19.7 | —19.6 | —0.1 | +0.2 | +0.1 |
| 19 | 12 50S | 30 30W | —19.1 | —18.8 | —19.0 | —19.1 | —0.3 | —0.1 | 0.0 |
| 19 | 12 53S | 31 28W | —18.6 | —18.4 | —18.7 | —18.5 | —0.2 | +0.1 | —0.1 |
| 20 | 12 52S | 32 18W | —18.1 | —18.2 | —18.0 | —18.3 | +0.1 | —0.1 | +0.2 |
| 21 | 12 53S | 34 21W | —17.8 | —17.0 | —16.8 | —17.2 | —0.8 | —1.0 | —0.6 |
| 21 | 12 55S | 35 09W | —16.5 | —16.3 | —16.8 | —16.3 | —0.2 | +0.3 | —0.2 |
| 22 | 13 02S | 36 00W | —16.2 | —16.0 | —16.4 | —15.9 | —0.2 | +0.2 | —0.3 |
| 23 | 13 16S | 37 39W | —15.1 | —15.0 | —15.3 | —14.7 | —0.1 | +0.2 | —0.4 |
| 24 | 13 06S | 38 35W | —14.4 | —14.1 | —14.7 | —14.1 | —0.3 | +0.3 | —0.3 |

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# MAGNETIC RESULTS OF HALLEY'S EXPEDITION, 1698-1700.

By L. A. Bauer.

It will be recalled that the noted astronomer, Edmund Halley, in 1698, was placed by King George III in command of the sailing ship, the *Paramour Pink*, for "proceeding with her on an expedition to improve the knowledge of the Longitude and variations of the Compasse." He was explicitly instructed that "in all the Course of your voyage you must be carefull to omit no opportunity of noting the variation of the Compasse, of which you are to keep a Register in your Journal."[1]

Halley's house at Oxford, showing his observatory on the roof. [View taken by L. A. Bauer, May, 1913.]

Halley set out on his first voyage from Deptford on October 20, 1698; returning to England towards the end of June, 1699, he sailed again from Deptford, September 16, 1699, this second voyage terminating at Long-reach, September 7, 1700. The two voyages together extended over the Atlantic Ocean from 50° N. to about 52° S. Halley's expedition is memorable as being the first scientific one sent out by any country with the specific object of ascertaining the direction in which a compass sets itself at various places; it was the first ocean magnetic survey. The expedition fully justified itself, not only in the results immediately obtained, but by the impetus given to further investigation in magnetism and other subjects. It seems strange, therefore, that Halley, though a prominent member of the Royal Society, published no report on his work. He appears to have been satisfied with the graphical representation of his magnetic results as shown on his famous chart—the first successful one of its kind—giving the lines of equal magnetic declination (variation of the compass) for the year 1700.

[1] *Cf. Terr. Mag.*, v. 16, p. 124.



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It was not until 1775 that Halley's journal—the Register in which he was instructed to note the "variation of the Compasse"—was published, and then by Alexander Dalrymple in his "Collection of Voyages chiefly in the Southern Atlantick Ocean." Halley's original journal was loaned to Dalrymple by the Board of Longitude.[2] As this particular book by Dalrymple has now become scarce, and as Halley's observed values of the magnetic declination are either not given at all, or but incompletely, in published collections of magnetic observations, such as for example, Hansteen's, and van Bemmelen's, it was thought desirable to make them known to readers of the Journal. (See pp. 126–132.)

The occasion was embraced at the same time by the compilers, Messrs. Ault and Wallis, members of the Department of Terrestrial Magnetism, to compute additional values of the magnetic declination from Halley's observed amplitudes of the Sun, which he does not appear to have reduced, and, furthermore, to revise the geographical positions, which, at times, required considerable correction. It was found worth while to spend the additional labor thus involved in the compilation. A careful scrutiny of Halley's results, obtained in the same locality at different times and at the intersections of his various cruises, as well as at ports where other data existed, showed that, considering all circumstances, he certainly had followed his instruction to observe "the variation of the Compasse with all the accuracy you can." Indeed, his work, though his instruments had not the refinement of modern ones, will yet compare favorably with that on some of our modern iron-clads, for the reason that his ship appears to have been almost a non-magnetic one—not by reason of special design, as in the case of the *Carnegie*, but because of the mode of construction at the time. His results for magnetic declination—this was the only magnetic element observed—appear to be reliable, as far as the examination could extend, to within one degree and even one-half degree, or as closely as he generally observed the Sun's amplitude.

The compilation is found to contain a number of important values of the magnetic declination at Atlantic ports and islands in the Atlantic Ocean. With the aid of these values it will be possible thus to extend backwards the established expressions for the

[2] Dalrymple found some portions of the Journal missing. Thus, he says, "The Journal of Dr. Halley's *first* Voyage is written on sundry *scraps* of paper, and some parts repeated in different places, and so blended that it was a very difficult matter to make it out intelligibly; I find no account at all of his departure from Barbadoes, so that there is a deficiency of a few days in this part of the voyage; and the conclusion is also wanting."

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secular variation of the magnetic declination at these places 100-150 years. At most of these places, the *Carnegie* and observers of the Department of Terrestrial Magnetism have recently made observations, so that the course of the secular variation can be followed here, with fair accuracy, for over two centuries.

## HALLEY'S VARIATION CHART.

The information as to mode of construction and date of issue of Halley's "Variation" or Isogonic[3] Chart for 1700 has also been very meager. In *Nature*, of May 23, 1895, p. 79, I made known the finding, in the British Museum, of a Halley isogonic chart which had escaped the attention of magneticians and bibliographers. Upon seeing the notice, Thos. Ward, Esq., of Northwich, England, made known in the following issue of the same periodical the fact that he likewise possessed a copy of this Halley chart and, through his courtesy, it was possible to give in the January, 1896, issue of *Terrestrial Magnetism* a facsimile reproduction reduced to about one-fifth of the original size.[4] During my recent visit to England (May-June, 1913) and in connection with the preparation of the Halley Lecture on Terrestrial Magnetism, delivered on May 22 at the University of Oxford,[5] I had occasion to ascertain some additional facts regarding Halley's observations and charts.

Appendix A contains extracts pertaining to Terrestrial Magnetism from the Journals of the Royal Society, in which mention is made of Edmund Halley, during, and subsequent to, the period of Halley's voyages and the issuing of his chart. These extracts were made from the Rigaud Papers at the Bodleian Library, Oxford, the privilege of examining which, through the kind offices of Prof. A. E. H. Love, F. R. S., was courteously extended to me by the Librarian, F. Maden, M. A., to whom I wish to acknowledge here my indebtedness. Some of the more important of these extracts were later verified by me from the original records at the Royal Society in Burlington House, London, through the courtesy of the Librarian, Mr. Harrison.

Minutes 1, 2, 3, 7, 8, and 13 refer to Halley's map which "shewed the Variations of the needle." Nos. 1 and 2, as Halley's voyages

[3] Halley gave no distinctive name to his lines. For some time they were referred to by others as the "Halleyan Lines." Hansteen introduced the term "isogonic."

[4] *Cf. Terr. Mag.*, v. 1, Jan., 1896, pp. 28-31 and frontispiece.

[5] Published in *Bedrock*, issue of October, 1913.

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were not concluded until Sept. 7, 1700, refer evidently to a manuscript map, which possibly at first only covered that part of the world—the Atlantic Ocean—embraced in his expedition. No. 3 states that "Capt. Halley produced a map wherein was the course they had held in his late voyage." Now, the only Halley map thus far known which contains the course of the *Paramour Pink* is the one above referred to, a copy of which, as stated, was originally found in the British Museum.[6] I have termed it the "Atlantic Chart," to distinguish it from the "World Chart," apparently issued later.[4]

From the recent search made in the four libraries, Bodleian (Oxford), Cambridge University Library, British Museum, and Library of Congress (Washington, D. C.), I have found that a copy of this "Atlantic Chart" formed the first map in the fourth book of "The English Pilot," published by W. Mount and T. Page in London, 1737. This "fourth book" contained maps solely pertaining to the Atlantic Ocean, "describing the West-India navigation, from Hudson's Bay to the river Amazones." This copy of the Halley "Atlantic Chart" was not given in the 1706 edition of the "English Pilot." I have thus far seen it in the editions of 1737 and 1753; in the 1755 and subsequent editions there is a revised isogonic chart for the Atlantic without, however, now being credited to or signed by Halley.

The copy of the Halley "Atlantic Chart" in "The English Pilot" for 1737, is precisely the same as that reproduced in this Journal,[4] except for a border text printed on the two sides of the chart, giving "The Description and Uses of a New and Correct SEA-CHART of the Western and Southern Ocean, shewing the Variations of the Compasse," signed, E. Halley. As this text may be Halley's first description of his chart, it is given in Appendix B; it does not appear to have been printed on the margins of the chart, when published separately, but it is possible that it may have been printed on a separate sheet to be attached to the chart. No date is given on the chart; however, it was dedicated to King William III, who fitted out Halley's expedition and who died March 8, 1702; the "Atlantic Chart," when sold separately, was, therefore, issued originally prior to March 8, 1702—probably in 1701.

Minute 7, June 4, 1701, records the presentation of Halley's map to the Society and "it was ordered to be hung in the meeting

Only the second voyage is laid down on Halley's map.

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room." Neither this copy nor the one which Halley presented to the Society on December 8, 1703 (Minute 13) could be found in the Royal Society rooms. The latter may have been Halley's more complete chart, embracing now the whole world—the "World Chart." Every copy of this Chart thus far seen by me in the libraries of Berlin, Hamburg, Paris, London, Oxford, Cambridge, and Washington is dedicated, "To His Royall Highness, Prince George of Denmark, Lord High Admirall of England, Generalissimo of all Her Majestie's Forces." Since Prince George, consort of Queen Anne, did not bear this title until April 17, 1702, the "World Chart," as far as the present evidence goes, must have been issued subsequent to this date. The earliest atlas in which I have thus far found the "World Chart" is the "Atlas Maritimus Novus or The New Sea-Atlas printed for Richard Mount and Thomas Page on Tower Hill MDCII," a copy of which was seen by me at the University Library, Cambridge, England, through the facilities courteously placed by the Librarian at my disposal, at the instance of Professor Sir Joseph Larmor, F. R. S., M. P. This atlas, as is seen, was published in 1702—probably, for the reason above given—near the middle or end of the year; Halley's "World Chart," in two sheets (20° W. to 160° E. and 160° E. to 20° W.), is in the front part of the Atlas.

Airy reproduced the "World Chart" in the Greenwich Observations of 1869, as he could find no one of his day who had ever seen a copy of Halley's magnetic chart. After some search in libraries at home and abroad, he found a copy in the British Museum which was then thought to be the only copy of the original edition.[7] Airy apparently was not aware of the "Atlantic Chart," and the date erroneously ascribed to the copy of the "World Chart" was 1701. Hellmann, in No. 4 of his valuable series of "Neudrucke von Schriften und Karten über Meteorologie und Erdmagnetismus," reproduced the "World Chart," making use of the photolithographic reproduction of the British Museum copy made for Airy in September, 1870. Hellmann's reprint was published

[7] The British Museum copy used by Airy is either that catalogued as number 974. (5) or 973. (15). The name of the selling agent is not given on these two copies, and they are the only ones thus far found in which this is the case; the size of these copies is 48 x 20½ inches. The copy in the "Atlas Maritimus, 1702," referred to above, as well as the Hamburg and Paris copies, and the copy in the Atlas containing the Mountaine and Dodson charts of 1744 and 1758, has printed in the legend over Brazil, in the free space under the year MDCC, "Sold by R. Mount and T. Page, on Great Tower Hill, London." The last three named copies have, furthermore, an extra strip pasted on the left side, embracing again the region 90° E. to 160° E., so that the chart extends now over 430° in longitude, instead of but 360°.

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shortly prior to the finding of the Halley "Atlantic Chart," and so he likewise gave the date 1701 to the "World Chart." Hellmann is to be credited with being the first to bring to light and to reproduce the border text to the "World Chart" found on the copy in the Hamburg Stadtbibliothek. In Appendix C, this text[8] is given as based on copies I have myself seen; the copy in Hellmann's reprint contains a few errors—possibly typographical ones in the original.

The reader will find some interesting information in the two texts (Appendices B and C), as well as certain secular variation data.

## Halley's Declination Observations at London.

The only values of the magnetic declination observed by Halley at London, thus far to be found in published compilations, are those given by Halley himself in his papers, in the *Philosophical Transactions* of 1683 and 1692, namely, 2° 30′ W in 1672, 4° 30′ W in 1683, and 6° 00′ W in 1692. Consulting, however, Appendix A, Minutes 5, 9, and 21, the following additional values are obtained, the first of which is of particular interest, as it gives some information as to the magnetic needles used by Halley on his expedition:

1701, May 7. Mr. Halley tried the experiment of the Variation of the Needle this day, with the two needles he had with him in his late Voyage: and by the one the Variation was 7° 40′, by the other 8° 00′ W.

1702, July 8. Mr. Halley observed the Variation of the Needle, which was found to be 8½° Westward, or very near it.

1716, May 24. Dr. Halley reported that he had drawn a Meridian Line on the stone erected in the Society's yard before the repository, and that the Variation was found at present to be full twelve degrees.

These additional values fall in well with those computed from the secular variation expressions established by Dr. Felgentraeger and myself on the basis of the data known at the time.[9]

In conclusion, the references to Halley's theory of the Aurora Borealis, contained in Appendix A, Minutes 19, 20, 22, 23, 26, and 28, will be of interest.

[8] I have not yet seen in the English libraries consulted a copy of Halley's "World Chart" which contains this border text, although from the Rigaud papers at the Bodleian Library the text, or description of Halley's Chart, was at one time in the British Museum. Rigaud says that "at the bottom of the chart there is added a strip of letter press of about six inches in breadth containing what has been copied." [The same text as given in Appendix C.]

[9] Bauer, L. A. Beiträge zur Kenntniss des Wesens der Säcular-Variation des Erdmagnetismus, pp. 14-17. Inaug. Diss. University Berlin, 1895.

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## *Appendix A.*

### EXTRACTS PERTAINING TO TERRESTRIAL MAGNETISM FROM THE JOURNALS OF THE ROYAL SOCIETY, IN WHICH MENTION IS MADE OF EDMUND HALLEY, JUNE 3, 1696 – DECEMBER 17, 1741.

| *No.* | *Date* | *Minute* |
|---|---|---|
| 1 | 1699 Aug. 16 | Mr. Halley shewed the several Variations of the Needle, he had observed in his voyage, set out in a sea chart, as also he shewed that Brazile was ill placed in the (ye) common Maps, and he shewed some Barnacles which he observed to be of quick growth. |
| 2 | 1700 Oct. 30 | Capt. Halley produced a map and shewed in it his observations on the Variation of the Magnetical Needle which he rectified in the Chart, as it was curiously laid down with Marks, etc., in this Map. |
| 3 | 1701 Feb. 5 | Capt. Halley shewed a Map, wherein was the course they had held in his late voyage, and where were noted Variations of the Needle, in several parts of the world; as also the true longitudes and latitudes of many places. |
| 4 | 1701 Feb. 5 | There was read an Advertisement concerning the latitude of the Lizard and Variation by Mr. Halley. He was thanked for this Communication, which was judged very useful to the public. |
| 5 | 1701 May 7 | Mr. Halley tried the experiment of the Variation of the Needle this day. with the two needles he had with him in his late Voyage: and by the one the Variation was 7° 40′, by the other 8° 00′ W. |
| 6 | 1701 May 14 | Mr. Halley said that the Needle with a counterpoise, he thought useful in observing the Variations in those parts of the world where the needle dips, and that it observes more exactly than the other sort of needle. |
| 7 | 1701 June 4 | Mr. Halley presented the Society with a Map of his late Voyage (Voiage) to the South. He was thanked for it, and it was ordered to be hung in the Meeting room. |
| 8 | 1702 June 17 | A letter was read from Dr. Wallis to Capt. Halley, concerning his map of Magnetic Variations and some other things relating to the magnet. |
| 9 | 1702 July 8 | Mr. Halley observed the Variation of the Needle, which was found to be 8½° Westward, or very near it. |
| 10 | 1702 July 15 | Mr. Halley said, that at the first observation of the needle it varied 11¼° East. [Borough's and Norman's observation of 1580.—L. A. B.] |
| 11 | 1702 May 27 | Mr. Julianus said that Dijou—a compass—in 20 years had changed or varied 8° W and as much East. Mr. Halley thought this alteration must have come from some iron placed in the neighbourhood of the needle. |

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| *No.* | *Date* | *Minute* |
|---|---|---|
| 12 | 1703 April 7 | Mr. Halley borrowed a paper concerning variations, formerly belonging to Mr. Hooke. |
| 13 | 1703 Dec. 8 | Mr. Halley presented his Map of the Variation to the Society. |
| 14 | 1711 July 12 | Transact. No. 292, it was very remarkable that the dipping of the needle in the latitude of 34° South, near the Cape of Good Hope, is but 48°, whereas going to the Eastward 78½° from the Cape in the S. |
| 15 | 1711 July 26 | Dr. Halley was desired to collect all the observations which have been made by the Royal Society of the Variation of the Needle, in order to have them published together in the Transactions. (Adjourned for the summer.) |
| 16 | 1711 Oct. 18 | The minutes of the last meeting being read and mention made of the variation of the needle, Dr. Halley was desired to take the variation this Year at Gresham College, and assist in fixing a new meridian in some convenient place, in the House or Repository of the Society in Crane Court, against the year ensuing. |
| 17 | 1712 March 20 | The president proposed that Dr. Halley and Mr. Hawksbee should try the power of the great loadstone at several distances to find the true proportion of its decrease, which he believed would be nearer the cubes than the squares. (March 27. Mr. Hawksbee alone was ordered to try the experiment.) |
| 18 | 1712 May 1 | A paper of the variation of the magnetic needle, observed by Capt. Woods Rogers in the South Sea, was read. It was delivered to Dr. Halley to peruse and consider. |
| 19 | 1716 March 8 | Dr. Halley produced a letter from Dr. Keile to himself from Oxford (on the Aurora of the 6th). |
| 20 | 1716 March 18 | Dr. Halley proposed for a solution of this strange appearance (of aurora borealis) that on certain occasions there may arise from the body of the earth such a vapour as arises from the bodies of comets and of which their tails are composed. This he supposed might bear a great analogy to the electrical effluvia of glass, etc., which emit such streams with great violence when rubbed, and said that the greatest intervals at which these lights are seen is an objection against any other solution that can be offered as well as this. |
| 21 | 1716 May 24 | Dr. Halley reported that he had drawn a Meridian Line on the stone erected in the Society's yard before the repository, and that the variation was found at present to be full twelve degrees. It was ordered to search the Books to see how it had encreased in the years past. |
| 22 | 1716 May 31 | Dr. Halley read a lecture upon the late wonderful phenomenon that was seen on the 6th of March. |
| 23 | 1719 Nov. 19 | Dr. Halley—accounts of a considerable aurora borealis seen in the west of England. Dr. Halley read a description of the same appearance seen at the same time by himself, etc. |

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| No. | Date | Minute |
|---|---|---|
| 24 | 1719 Dec. 24 | Dr. Halley produced a paper containing some observations made by Capt. Cornwall upon the variations of the needle in the East Indies in the years 1707, 1708, and 1709. |
| 25 | 1726 Feb. 17 | A table of magnetical variations as they were found between London and Hudson's Bay by the observations of Capt. Chr. Middleton between the years 1721 and 1725, was communicated by Dr. Halley. |
| 26 | 1726 Nov. 10 | Dr. Halley related a material circumstance observed in the late aurora borealis, which serves to confirm him in his former opinion, that the magnetical effluvia of the earth are concerned in the production of the phenomenon, and that was from the situation of the luminous arch in the north and the tendency of the motion of the striæ, both which seemed to have a dependence upon the magnetical virtue. He said the arch was highest in that place where it crossed the magnetical meridian, and the striæ had a motion with an inclination like that of the magnetical dipping needle. But for the clearer proof of these particulars he referred to a discourse which he is now preparing to lay before the Society. |
| 27 | 1728 Feb. 15 | Dr. Halley communicated a journal of observations of the variation of the compass from the 13th February, 1724, to the 18th August, 1727, in an East India voyage from the Cape de Verd Islands to Madras and from Madras to England (See March 21). |
| 28 | 1728 Nov. 21 | A letter from Mr. Derham was read on an aurora borealis. Dr. H. upon reading this letter took occasion to confirm the truth of a remark which he formerly made concerning these appearances and which seems to show that this phenomenon has some relation or dependence on the magnetic quality of the earth, for he said that it has ever been observed since he first took notice of it that the center of the luminous arch and black basis always lies in the magnetical meridian, and seems to change its place in the horizon as that alters, as far as can be observed. |
| 29 | 1731 Jan. 21 | Two papers were read by Capt. Hammond to account for the variation of the needle. This hypothesis is the same in all its essential parts with that delivered by Dr. Halley in the Phil. Trans. No. 195, printed in the year 1692, a sight of which the author confesses to have had after he had composed his own theory, as also to have received some hints concerning the same from Dr. Halley twenty years before he writ his discourse, and says he fell upon this hypothesis by considering a certain set of observations of the variation of the needle therein recited: which happens to be the very same set as is made use of by Dr. Halley in that Transaction, as the ground work upon which he raised his own hypothesis—but he claims to give a more precise determination of certain circumstances left by Dr. Halley to future observation.<br>It differs from Dr. Halley's in the supposed position of the poles; in considering the fixt poles as of much greater strength than the moveable poles of the nucleus. |
| 30 | 1732 Nov. 16 | Dr. Halley communicated a paper on observations of latitudes and variations taken on board the Hartford on her passage from Java Head to St. Helena, A. D. 1731-2. |
| 31 | 1732 Dec. 14 | Regarding effect of lightning on magnetic needles. |



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## *Appendix B.*

### The Description and Uses of a New and Correct *SEA-CHART* of the Western and Southern OCEAN, shewing the Variations of the *Compass.*

The Projection of this *Chart* is what is commonly called *Marcator's;* but from its particular Use in *Navigation,* ought rather to be named the *Nautical;* as being the only true and sufficient *CHART* for the *Sea.* It is supposed, that all such as take Charge of Ships in long Voyages, are so far acquainted with its Use, as not to need any Directions here. I shall only take the Liberty to assure the Reader, that having taken all possible Care, as well from Astronomical Observations, as Journals, to ascertain the Scituation and Form of this *Chart,* as to its principal Parts, and the Dimensions of the several Oceans; he is not to expect that we should descend to all the Particularities necessary for the Coaster, our Scale not permitting it. What is here properly new, is the *Curve-Lines* drawn over the several Seas, to shew the Degrees of the *Variation* of the *Magnetical Needle,* or *Sea Compass:* which are design'd according to what I my self found in the *Western* and *Southern* Oceans, in a Voyage I purposely made at the Publick Charge in the Year of our Lord 1700.

That this may be the better understood, the curious Mariner is desired to observe, that in this *Chart* the Double Line passing near *Bermudas,* the Cape *Verde Isles,* and Saint *Helena* every where divides the *East* and *West Variation* in this *Ocean,* and that on the whole Coast of *Europe* and *Africa* the *Variation* is Westerly, as on the more Northerly Coasts of *America,* but on the more Southerly Parts of *America* 'tis Easterly. The Degrees of *Variation,* or how much the Compass declines from the true North on either Side is reckoned by the Number of the Lines on each side the double Curve, which I call the *Line* of *No Variation;* on each fifth and tenth is distinguished in its Stroak, and numbered accordingly, so that in what Place soever your Ship is, you find the *Variation* by Inspection.

That this may be the fuller understood, take these Examples. At *Madera* the *Variation* is 30½d.* West; at *Barbados* 5½d. East; at *Annabon* 7d. West; at Cape *Race* in *Newfoundland* 14d. West; at the Mouth of *Rio de Plata* 18d. East, &c. And this may suffice by Way of Description.

As to the Uses of this *Chart,* they will easily be understood, especially by such as are acquainted with the Azimuth Compass, to be, to correct the Course of Ships at Sea: For if the Variation of the Compass be not allowed, all Reckonings must be so far erroneous: And in continued Cloudy Weather, or where the Mariner is not provided to observe this Variation duly, the *Chart* will readily shew him what Allowances he must make for this Default of his Compass, and thereby rectify his Journal.

* This is a misprint and should be 3½d. The copy in "The English Pilot," 1737 (maps 97. C. 20), consulted at the British Museum, has been pen-corrected.—L. A. B.

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But this Correction of the Course is in no case so necessary as in running down on a Parallel *East* or *West* to hit a *Port:* For if being in your Latitude at the Distance of 70 or 80 Leagues, you allow not the Variation, but steer East or West by Compass, you shall fall to the Northwards or Southwards of your Port on each 19 Leagues of Distance, one Mile for each Degree of Variation, which may produce very dangerous Errors, where the Variation is considerable; for Instance, having a good Observation in Latitude 49d. 40m. about 80 Leag. without *Scilly*, and not considering that there is 8 Degrees West Variation, I steer away *East* by Compass for the Channel; but making my way truly *E.* 8d. *N.* when I come up with *Scilly*, instead of being 3 or 4 Leagues to the South thereof, I shall find my self as much to the Northward: And this Evil will be more or less according to the Distance you sail in the Parallel. The Rule to apply it is, That to keep your Parallel truly, you go so many Degrees to the Southward of the *East*, and Northward of the *West*, as in the *West Variation;* but contrariwise, so many Degrees to the Northwards of the *East*, and Southwards of the *West*, as there is *East Variation.*

A further Use is in many Cases to estimate the Longitude at Sea thereby; for where the *Curves* run nearly *North* and *South*, and are thick together, as about Cape *Bona Esperance*, it gives a very good Indication of the Distance of the Land to Ships come from far; for there the Variation alters a Degree to each two Degrees of Longitude nearly; as may be seen in the *Chart.* But in this Western *Ocean*, between *Europe* and the *North America*, the Curves lying nearly East and West, cannot be Serviceable for this Purpose.

This Chart, as I said, was made by Observation of the Year 1700, but it must be noted, that there is a perpetual tho' slow Change in the *Variation* almost every where, which will make it necessary in time to alter the whole System: at present it may suffice to advertise that about *C. Bonne Esperance*, the West Variation encreases at the Rate of about a Degree in 9 Years. In our Channel it encreases a Degree in seven Years, but slower the nearer the Equinoctial Line; as on the *Guinea* Coast a Degree in 11 or 12 Years. On the *American side* the *West Variation* alters but little; and the *East Variation* on the *Southern America* decreases, the more Southerly the faster; the *Line of No Variation* moving gradually towards it.

I shall need to say no more about it, but let it commend it self, and all knowing Mariners are desired to lend their Assistance and Informations, towards the perfecting of this useful Work. And if by undoubted Observations it be found in any Part defective, the Notes of it will be received with all grateful Acknowledgement, and the Chart corrected accordingly. E. HALLEY.

This CHART is to be sold by *W. Mount*, and *T. Page*,
at the *Postern* on *Tower-Hill.*

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*Appendix C.*

The Description and Uses of a New and Correct *SEA-CHART* of the Whole World, shewing the Variations of the *COMPASS.*

The Projection of this Chart is what is call'd *Mercator's;* but from its particular Use in *Navigation,* ought rather to be nam'd the *Nautical;* as being the only True and Sufficient Chart for the Sea. It is suppos'd, that all such as take Charge of Ships in long Voyages, are so far acquainted with its Use, as not to need any Directions here. I shall only take the liberty to assure the Reader, that having taken all possible Care, as well from Astronomical Observations as Journals, to ascertain the Situation and Form of the *Whole World,* as to its Principal Parts, and the Dimensions of the several Oceans; He is not to expect that we should descend to all the Particularities necessary for the Coaster, our Scale not permitting it. What is here properly *New,* is the *Curve Lines* drawn over the several Seas, to shew the degrees of the *Variation* of the *Magnetical Needle,* or *Sea-Compass:* Which are design'd according to what I my self found, in the *Western* and *Southern* Oceans, in a Voyage I purposely made at the Publick Charge, in the year of our Lord 1700; or have Collected from the Comparison of several Journals of Voyages lately made in the *Indian* Seas, adapted to the same year.

That this may be better understood, the Curious Mariner is desired to observe, that in this Chart the Double Line passing near *Bermudas,* the *Cape de Verde Isles,* and St. *Helena,* every where divides the *East* and *West* Variation in *this Ocean,* and that on the whole Coast of *Europe* and *Africa* the Variation is Westerly, as on the more Northerly Coast of *America,* but on the more Southerly Parts of *America* 'tis Easterly. The Degrees of Variation, or how much the Compass declines from the true North on either side, is reckon'd by the Number of the Lines on each side the Double Curve, which I call the *Line* of *No Variation;* and each fifth and tenth is distinguished in its Stroak, and numbred accordingly: So that in what Place soever your Ship is, you find the Variation by Inspection. The like is to be observed in the *Indian* Ocean, where the *Variation* is altogether *Westerly,* increasing till you come about the Meridian of the East - part of St. *Lawrence* or *Madagascar* (where 'tis of about two Points) and thence it decreases till you arrive on the East - Coast of *China,* or at the *Philippine - Isles.* Here another double Line on which there is *No Variation* divides again the West from the *East* Variation, that in all propability is to be met with almost all over that Immense Ocean we commonly call the *South - Sea;* but I have not attempted to describe the Curves therein, wanting Accounts and Journals to ascertain the same.

In the *Mediterranean* the Degrees of *Westerly* Variation are all marked and numbred from 5 *deg.* at *Malaga,* to 12 *deg.* at *Cyprus.* In the *Baltick* from 8 *deg.* to 10 *deg.* In the *Red Sea* from 12 *deg.* to 16

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*deg.;* and in the *Persian Gulf* from 13 to 14 *degrees*, all *Westerly*. That this may be the fuller understood, take these Examples. At *Madera* the Variation is 3 *deg.* ½ *West;* at *Barbadoes* 5 *deg.* ½ East; at *Annobon* 7 *deg. West;* at *Diego Roiz* 19 *deg.* West; at *Cape Raze* in *Newfound-land* 14 *deg. West;* at the Mouth of *Rio de Plata* 18 *deg. East;* at *Java head* 2 *deg.* ½ West, etc. And this may suffice by way of Description.

As to the Uses of this Chart, they will be easily understood, especially by such as are acquainted with the Azimuth Compass, to be to correct the Courses of Ships at Sea, For if the *Variation* of the Compass be not allowed, all Reckonings must be so far erroneous: And in continued cloudy Weather, or where the Mariner is not provided to observe this Variation duly, the Chart will readily shew him what Allowances he must make for this Default of his Compass, and thereby rectify his Journal.

But this Correction of the *Course* is in no case necessary, as in running down on a Parallel *East* or *West* to hit a *Port:* For if being in your Latitude, at the Distance of 70 or 80 Leagues, you allow not the Variation, but steer East or West by Compass, you shall fall to the Northwards or Southwards of your Port, on each 19 Leagues of Distance, one Mile for each Degree of Variation, which may produce very dangerous Errors, where the Variation is considerable. For instance. Having a good Observation in Latitude 49 *deg.* 40 *min.* about 80 Leagues without *Scilly*, and not considering that there is 8 Degrees West *Variation,* I steer away East by Compass for the Channel; but making my way truly *E.* 8 *deg. N.* when I come up with *Scilly*, instead of being 3 or 4 Leagues to the South thereof, I shall find my self as much to the Northward: and this Evil will be more or less, according to the Distance you sail in the Parallel. The Rule to apply it is, That to keep your Parallel truly, you go so many Degrees to the *Southward* of the *East,* and *Northward* of the *West,* as is the *West Variation:* but contrariwise, so many Degrees to the *Northwards* of the *East,* and *Southwards* of the *West,* as there is *East Variation.*

A further Use is in many cases to estimate the Longitude at Sea thereby; for where the Curves run nearly *North* and *South*, and are thick together, as about *C. Bonne Esperance,* it gives a very good Indication of the Distance of the Land, to Ships come from far; for there the Variation alters a Degree to each two Degrees of Longitude nearly; as may be seen in the Chart. But in this *Western* Ocean, between *Europe* and the *North America,* the Curves lying nearly East and West, cannot be serviceable for this purpose.

This Chart, as is said, was made by Observations of the Year 1700, but it must be noted, that there is a perpetual, tho' slow Change in the *Variation* almost every where, which will make it necessary in time to alter the whole System: At present it may suffice to advertise, that about *C. Bonne Esperance,* the West Variation increases at the Rate

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of about a Degree in nine Years. In our Channel it increases a degree in Seven Years, but slower the nearer the Equinoctial Line, as on the *Guiney* Coast a Degree in 11 or 12 Years. On the *American Side* the *West Variation* alters but little; and the *East Variation* on the *Southern America decreases*, the more Southerly the faster; the *Line of No Variation* moving gradually towards it. In the *Indian Seas*, after you pass St. *Lawrence*, the *West Variation* is on the decrease, the faster the more Westerly and Southerly; and it is in a manner at a stand when you come to the length of *Java*.

I shall need to say no more about it, but let it commend it self, and all knowing MARINERS are desired to lend their Assistance and Information, towards the perfecting of this Useful Work. And if by undoubted Observations it be found in any Part defective, the Notes of it will be received with all grateful Acknowledgement, and the Chart Corrected accordingly. *E. HALLEY.*

This *CHART* is to be Sold by RICHARD MOUNT and THOMAS PAGE, at the *Postern* on *Tower-Hill*.*

*According to the Hamburg text, reproduced by Hellmann, "This *CHART* is Sold by THOMAS PAGE and WILLIAM MOUNT in *Postern-Row, Tower-Hill*," and on the Paris text it is stated that "This *CHART* is Sold by R. and W. MOUNT and T. PAGE, in *Postern-Row, Tower-Hill*." It would seem as though Richard Mount and Thomas Page were the first publishers of this World Chart and text.—L. A. B.

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## HALLEY'S OBSERVATIONS OF THE MAGNETIC DECLINATION, 1698–1700.

COMPILED AND REVISED BY J. P. AULT AND W. F. WALLIS.

### Explanation of Table and Methods.

The spelling of the ports visited by Halley's ship, the *Paramour Pink*, was modernized. It was thought desirable, however, to retain Halley's dates as given by him, which apply to the old style calendar; to refer them to the new style calendar, it would be necessary to add 10 days in 1698-99 and 11 days in 1700.

The latitudes and longitudes, given in the columns headed "Halley's noon position", are those as published in Halley's journal, all his reckoning being made from noon to noon. The latitude usually results from "a good observation" at noon and the longitude is obtained by reckoning from the previous noon position, except in a very few cases as described in the footnotes.

In the column headed "corrected position for place of observation", the attempt was made to obtain as correct a position as possible for the place where the magnetic declination was observed. Halley's noon latitudes, accepted as observed, were referred to the place of observation by direct interpolation. Longitudes at the various ports of call were scaled from the best maps available and the outstanding differ-

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ence between Halley's reckoned longitude and the correct longitude was allowed as linear change, or as a constant set per day, from port to port. Whenever the observation was taken in the morning alone, the position was obtained by a straight interpolation of one-fourth the distance from the noon position of the day in question to the noon position of the preceding day. A similar interpolation was made ahead to the noon position of the following day, when the observation was made in the evening. The "corrected positions", in the nature of the case, must still, of course, be regarded as only approximations to the true ones.

Values of the magnetic declination were obtained in nearly all cases by observing the Sun's magnetic amplitude at sunrise or at sunset. An evening amplitude was combined with the one on the following morning, one-half the difference between the two amplitudes being taken as the magnetic declination, and being applied to the geographical position at midnight. Or, when morning and evening amplitudes were observed on the same day, the half difference was taken as the magnetic declination and applied to the position at noon. On several days the magnetic declination was obtained by observing the azimuth of the Sun or Moon, when at a low altitude above the horizon, as cloudy and foggy weather prevented taking the Sun's amplitude.

Frequently the amplitudes were given but the resulting magnetic declinations, for some reason, were not entered in Halley's journal. The magnetic declinations were computed from these amplitudes according to Halley's methods; the additional values thus obtained are italicized. The true amplitudes were obtained from Table 39 in Bowditch's "The American Practical Navigator", which usually checks Halley's results to within one-tenth degree. This table also shows that, as Halley's results need no correction for atmospheric refraction, he observed the amplitude of the Sun when on the true horizon. In this connection it is of interest to give here the following quotation from Halley's communication to the Royal Society in 1692 on "An Account of the Cause of the Change of the Variation of the Magnetical Needle":

> And by the way it will not be amifs to amend a receiv'd Error in the Practice of obferving the Variation, which is, to take it by the Amplitude of the Rifing and Setting Sun, when his Center appears in the vifible Horizon; whereas he ought to be obferv'd when his under Limb is ftill above the Horizon about ⅓ of his Diameter, or twenty Minutes, upon the fcore of the Refraction, and the height of the Eye of the Obferver above the Surface of the Sea: Or elfe they are to work the Amplitudes as they do the Azimuth, reckoning the Sun's Diftance from the Zenith 90° 36′: This, though it be of little confequence near the Aequinoctial, will make a great Error in high Latitudes, where the Sun rifes and fets obliquely.

In the column, headed "Wind", are given the directions of the winds which Halley records in his Journal each day as having prevailed during the preceeding 24 hours.

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TABLE I. *Magnetic declinations observed by Dr. Edmund Halley, 1698–99. (First Voyage.)*

| Place | Date (old style) | Halley's noon position | | Corr'd position for place of observation | | Magnetic Declination | Sun's amplitude. A. or P. M. | Wind | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | Lat. | Long. W. of London | Lat. | Long. W. of Greenwich | | | | |
| | 1698 | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | | | |
| River Thames | Oct. 27 | ..... | ..... | 51 30N | 359 20 | 7 W | ..... | SSW | Position approx. |
| Portland Road | Nov. 1 | ..... | ..... | 50 30N | 2 20 | 6½ W | ..... | | " " |
| Portsmouth Harbor | 10 | ..... | ..... | 50 50N | 1 05 | 7 W | ..... | NNE | " " |
| At sea | Dec. 5 | 42 38N | 10 09 | 43 10N | 10 07 | 5 30W | A | ENE | |
| " " | 8 | 39 28N | 12 25 | 39 39N | 12 16 | 5 00W | A | SxW to E | |
| " " | 10 | 36 06N | 11 57 | 36 06N | 11 57 | 4 20W | A&P | ENE | |
| Town of Funchal | 20 | 32 30N | 16 45 | 32 37N | 16 55 | 4 00W | | | On shore |
| At sea | 28 | 21 12N | 21 51 | 21 12N | 22 36 | 2 00W | A&P | NNE, NE | |
| | 1699 | | | | | | | | |
| Island of Sal | Jan. 1 | 16 40N | 22 | 16 45N | 22 55 | 0 30W | ..... | ..... | Close under lee of island |
| Bay of Praya | 6 | 14 50N | 22 30 | 14 53N | 23 30 | *0 32*W | A | ..... | |
| At sea | 9 | 8 28N | 18 12 | 8 28N | 19 44 | 1 W | ..... | ..... | |
| " " | 14 | 4 40N | 15 05 | 4 40N | 17 30 | 0 00 | ..... | ..... | |
| " " | 23 | 2 57N | 15 40 | 2 57N | 19 40 | 0 00 | ..... | ..... | |
| " " | Feb. 1 | 1 11N | 18 33 | 1 09N | 24 14 | 1 E | P | SSW to SExE | |
| " " | 3 | 0 26N | 19 22 | 0 26N | 25 19 | 1½ E | A&P | SExS | |
| " " | 8 | 0 34 S | 20 12 | 0 26 S | 27 00 | 1½ E | A | ESE | |
| " " | 12 | 1 55 S | 20 57 | 1 55 S | 28 30 | 2½ E | A&P | SxE, SExS | |
| " " | 15 | 3 26 S | 21 09[1] | ..... | ..... | ..... | ..... | NNE, ESE | |
| Fernando do Noronha | 19 | 3 57 S | 23 40 | 3 50 S | 32 25 | 3 E | ..... | ..... | On shore; "not fully 3°" |
| Coast of Brazil | Mar. 5 | 7 06 S | 25 20[2] | 7 00 S | 34 50 | 2 44 E | ..... | ..... | "Accurately observed on shore" |
| At sea | 18 | 1 51 S | 35 21 | 1 51 S | 35 36 | 3 E | ..... | NNE, NExE | |
| " " | 25 | 5 37N | 44 17 | 5 37N | 46 10 | 4 E | A&P | ..... | |
| " " | 27 | 8 10N | 47 20 | 8 10N | 49 41 | 5 00 E | ..... | ..... | "Carefully observed" |
| " " | 28 | 9 25N | 48 53 | 9 25N | 51 29 | 5¼ E | ..... | ..... | |
| " " | 30 | 11 32N | 51 33 | 11 32N | 54 34 | ½ Pt. E | ..... | ..... | |
| " " | Apr. 1 | 13 14N | 55 16 | 13 14N | 58 48 | 4 45 E | ..... | ..... | |
| Bridgetown, Barbados | 2 | ..... | 56 05[3] | 13 04N | 59 37 | 5 00 E | ..... | ..... | "Several times observed, both on board and ashore" |

(Here some part of the Journal is missing.)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Antigua | Apr. 23 | ..... | ..... | 17 04N | 62 00 | 5 00 E | ..... | ..... | "Variation often observed" |
| Old Road, St. Christopher's | 30 | 17 30N | ..... | 17 18N | 62 47 | 5 30 E | ..... | ..... | |
| Road of Anguilla | May 7 | 18 20N | 62 50 | 18 10N | 63 15 | 5 15 E | ..... | ..... | "By several observations" |
| At sea | 11 | 21 42N | 63 20 | 22 07N | 63 51 | 4 15 E | P | ExN | |
| " " | 12 | 23 23N | 63 42 | 23 36N | 64 11 | 3 15 E | P | ExN | |
| " " | 13 | 24 20N | 63 56 | 24 20N | 64 21 | 2 30 E | A&P | ExN | |
| " " | 16 | 27 52N | 63 44 | 27 52N | 64 09 | 1 00 E | A&P | WxN, W | |
| " " | 18 | 30 41N | 63 35 | 31 13N | 63 56 | 0 00 | P | W-S-W | |
| " " | 19 | 31 45N | 63 27 | | | | A | W, WNW | |
| " " | 23 | 34 33N | 60 55 | | | | P | N to ExN | |
| " " | 24 | 34 56N | 60 57 | 34 44N | 61 21 | 3 00W | A | ENE | |
| " " | 24 | 34 56N | 60 57 | | | | P | ENE | |
| " " | 25 | 35 35N | 60 20 | 35 16N | 61 04 | 3 30W | A | SxW, SW | |
| " " | 26 | 36 57N | 58 40 | 36 36N | 59 30 | 4 30W | A | SW, NWxW | |
| " " | 31 | 39 50N | 50 53 | 39 50N | 51 18 | 6 30W | A&P | WSW, SxW | |
| " " | June 2 | 40 47N | 47 03 | 40 56N | 47 20 | 7 00W | P | WxN | |
| " " | 4 | 41 50N | 45 07 | 42 04N | 45 01 | 9 20W | P | SE, SSE | |
| " " | 6 | 43 20N | 41 42 | 43 11N | 42 27 | 10 20W | A | WNW, NNW | |
| " " | 11 | 47 25N | 27 05 | 47 16N | 28 12 | 8 30W | A | WxS | |
| " " | 13 | 48 40N | 20 00 | 48 54N | 19 07 | 8 30W | P | NWxW | |
| " " | 14 | 49 08N | 17 25 | | | | A | WxN, SSW | |
| " " | 18 | 49 37N | 7 48 | 49 36N | 7 37 | 6 25W | P | SExS to NNW | |
| " " | 20 | 49 57N | 3 32 | 49 51N | 4 19 | 5 40W | A | W, WxN | |

(The rest of the Journal is missing.)

[1] By occultation of star by the moon, "I conclude myself 160 leagues more westerly than our account, *and but* 50 leagues to the east of Fernando do Loronho." [2] Longitude = 36° by observations of occultation of star by the moon Feb. 25, and of eclipse of moon Mar. 5; "Wherefore we have been set by the *Currents* to the Westwards, during the long calms, *not less than 200 leagues*." [3] Longitude = 59° 05′ by observation of the "Emersion of Jupiter's Satellite." "Set about 3° to the Westward in this run" from Brazil to Barbados.

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TABLE II. *Magnetic declinations observed by Dr. Edmund Halley, 1699–1700. (Second Voyage.)*

| Place | Date (old style) | Halley's noon position | | Corr'd position for place of observation | | Magnetic Declination | Sun's amplitude, A. or P. M. | Wind | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | Lat. | Long. W. of London | Lat. | Long. W. of Greenwich | | | | |
| | 1699 | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | | | |
| The Downs | Sep. 27 | ..... | ..... | 51 15N | 358 30 | 7 32W | A | ESE | Position approxim'te |
| At sea | Oct. 1 | 46 33N | 10 10 | 46 20N | 10 40 | 6 07W | P | ..... | |
| " " | 2 | 45 22N | 11 05 | 45 16N | 11 35 | 6 24W | P | NW, WNW | |
| " " | 6 | 40 29N | 15 47 | 41 00N | 16 07 | 4 42W | A | NE | |
| " " | 7 | 39 52N | 16 13 | 39 34N | 16 49 | 3 28W | P | Calm | |
| " " | 8 | 38 39N | 15 56 | 38 25N | 16 45 | 3 45W | P | W to SW | |
| " " | 14 | 30 52N | 17 35 | 30 28N | 18 42 | *2 00*W | P | N, NxE | |
| " " | 15 | 29 17N | 17 31 | 29 41N | 18 43 | 1 58W | A | ..... | |
| " " | 16 | 27 36N | 17 30[1] | 27 36N | 18 47 | ..... | ..... | ..... | |
| Island of Sal | 23 | 16 40N | 23 00 | 16 44N | 23 00 | 0 55W | P | ..... | |
| " " " | 24 | 16 40N | 23 00 | | | | A | ..... | |
| Bay of Praya | 26 | 14 50N | 23 30 | 14 54N | 23 30 | 0 00 | A | ..... | |
| At sea | Nov. 11 | 2 42N | 20 37 | 2 42N | 21 49 | *1 20* E | A&P | SSE | "Good observations" |
| " " | 12 | 2 21N | 21 15 | 2 17N | 22 35 | *1 45* E | P | SSE, SxE | |
| " " | 16 | 0 12N | 23 22 | 0 09 S | 25 21 | 2 00 E | P | SExE | |
| " " | 17 | 0 30 S | 24 04 | | | | A | SExE | |
| " " | 17 | 0 30 S | 24 04 | 0 43 S | 25 52 | 2 00 E | P | SExE | |
| " " | 18 | 1 22 S | 24 42 | 1 50 S | 26 54 | 2½ E | P | SExE, ESE | |
| " " | 19 | 2 17 S | 25 30 | | | | A | SE, SExS | |
| " " | 21 | 3 50 S | 26 49 | 4 24 S | 29 04 | 3 E | P | SE | |
| " " | 22 | 4 58 S | 27 14 | | | | A | ExS, ESE | |
| " " | 22 | 4 58 S | 27 14 | 5 15 S | 29 23 | *3 20* E | P | ExS, ESE | "Very carefully observed" |
| " " | 24 | 7 22 S | 27 55 | 7 22 S | 30 10 | *4 12* E | A&P | ESE, SExE | |
| " " | 25 | 8 18 S | 28 15 | 8 18 S | 30 29 | *4 26* E | A&P | ESE, ExS | |
| " " | 26 | 9 12 S | 28 26 | 9 12 S | 30 45 | *5 00* E | A&P | ExS | |
| " " | 27 | 10 55 S | 28 36 | 10 55 S | 31 00 | *5 35* E | A&P | ExN, ENE | |
| " " | 28 | 12 51 S | 28 24 | 13 17 S | 30 57 | 5 30 E | P | ENE | "Very exactly taken" |
| " " | 29 | 14 36 S | 28 19 | 15 29 S | 31 04 | 6½ E | P | E | "As near as can be observed" |
| " " | 30 | 16 22 S | 28 30 | | | | A | ExN | |
| " " | 30 | 16 22 S | 28 30 | 17 08 S | 31 25 | 7 10 E | P | ExN | "Very accurately observed and adjusted, suppose in Lat. 17°" |
| " " | Dec. 1 | 17 55 S | 28 49 | | | | A | ExN, E | |
| " " | 1 | 17 55 S | 28 49 | 18 13 S | 31 42 | *7 20* E | P | ExN, E | |
| " " | 2 | 19 06 S | 29 24 | 19 20 S | 32 35 | 8 E | P | NE to ESE | |
| " " | 3 | 20 00 S | 30 16 | 20 30 S | 33 44 | 9 30 E | P | NE | |
| " " | 4 | 20 58 S | 31 13[2] | | | | A | NE | |
| " " | 4 | 20 58 S | 31 13 | 21 24 S | 34 44 | *10 03* E | P | NE | |
| " " | 5 | 21 49 S | 37 27 | | | | A | NExN to NxE | |
| " " | 5 | 21 49 S | 37 27 | 22 03 S | 35 41 | *9 45* E | P | NExN to NxE | |
| " " | 6 | 22 44 S | 39 32 | 22 43 S | 37 40 | 11¼ E | P | NNW to NxW | |
| " " | 7 | 22 41 S | 40 44 | 22 42 S | 39 05 | *10 30* E | P | N to NxW,WNW | |
| " " | 9 | 22 50 S | 42 28 | 22 41 S | 40 38 | *11 07* E | P | N to NWxN | |
| Off Rio de Janeiro | 13 | 23 02 S | 44 28 | 23 05 S | 42 58 | 11 30 E | P | ExN, NxE | |
| " " " " | 14 | 23 08 S | 44 41 | | | | A | WSW, WNW | |
| Rio de Janeiro | 14 | ..... | 44 45 | 22 54 S | 43 10 | ..... | ..... | ..... | No "variation" ashore given. Part of journal missing |
| Off Rio de Janeiro | 29 | ..... | ..... | 23 00 S | 42 50 | 11 46 E | P | ..... | |
| | 1700 | | | | | | | | |
| At sea | Jan. 1 | 24 06 S | 45 15 | 24 12 S | 43 18 | 12 04 E | P | SSE to SxW | |
| " " | 2 | 24 28 S | 44 39 | 24 38 S | 42 46 | 12 10 E | P | SSE to SSW | "By a very good observation" |
| " " | 3 | 25 08 S | 44 45 | 25 24 S | 42 51 | 12 40 E | P | S, E, NE | |

[1] Longitude = 19° from bearings on the islands of Palma and Ferro. "Reckoning 1° 30′ in error."

[2] Longitude = 36° 35′ by observation of occultation of star by the Moon.



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TABLE II.—*Continued.*

| Place | Date (old style) | Halley's noon position | | Corr'd position for place of observation | | Magnetic Declination | Sun's amplitude, A. or P. M. | Wind | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | Lat. | Long. W. of London | Lat. | Long. W. of Greenwich | | | | |
| | 1700 | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | | | |
| At sea | Jan. 4 | 26 10 S | 45 15 | 26 30 S | 43 13 | 13 00 E | P | E to NNE | "Both very good observations" |
| " " | 5 | 26 50 S | 45 35 | | | | A | NNE to NNW, SE, E | |
| " " | 5 | 26 50 S | 45 35 | 26 57 S | 43 27 | *13 15* E | P | NNE to NNW, SE, E | |
| " " | 7 | 27 57 S | 46 19 | 28 05 S | 43 53 | *13 23* E | P | S to SExE | |
| " " | 8 | 28 29 S | 46 29 | 28 52 S | 43 56 | 14 00 E | P | S, SSE, ESE | "Very exact" |
| " " | 9 | 29 14 S | 46 50 | | | | A | ESE, ExN | |
| " " | 9 | 29 14 S | 46 50 | 29 34 S | 44 19 | 14 05 E | P | ESE, ExN | |
| " " | 10 | 30 32 S | 47 33 | 31 08 S | 45 02 | 15 00 E | P | E, ENE, NE | |
| " " | 11 | 31 45 S | 48 15 | | | | A | NE to E | |
| " " | 11 | 31 45 S | 48 15 | 32 14 S | 45 37 | *14 49* E | P | NE to E | |
| " " | 12 | 33 41 S | 49 24 | 34 09 S | 46 40 | *15 16* E | P | E to NE | |
| " " | 15 | 37 44 S | 51 08 | 37 50 S | 47 51 | *16 47* E | P | All around the compass | |
| " " | 16 | 38 06 S | 51 28 | 38 46 S | 47 54 | 17½ E | P | SE to ExS | |
| " " | 17 | 39 27 S | 51 24 | | | | A | NE to NW | |
| " " | 18 | 41 40 S | 51 10 | 42 06 S | 46 54 | 19 16 E | P | NNW to WNW, NW | |
| " " | 19 | 42 32 S | 50 10 | | | | A | SWxS | By azimuth of sun at 5h 0m |
| " " | 19 | 42 32 S | 50 10 | 42 52 S | 45 58 | 20 15 E | P | SWxS | "Both very good observations" |
| " " | 20 | 43 12 S | 49 32 | | | | A | SWxS, SW, S, SxW | |
| " " | 21 | 44 22 S | 49 29 | 44 04 S | 45 28 | 21 10 E | A | NW | |
| " " | 25 | 48 42 S | 44 51 | 49 10 S | 39 48 | 22 00 E | P | SSW to S | |
| " " | 26 | 49 37 S | 43 50 | | | | A | S,W,NW,WNW | |
| " " | 30 | 51 52 S | 36 56 | 51 59 S | 31 13 | 19 00 E | P | W to S, E | "Well observed." |
| | 31 | 52 06 S | 35 42 | | | | A | E, ExS, N, NWxN | "Thick fog till night" |
| " " | Feb. 9 | 45 13 S | 28 05 | 44 57 S | 21 37 | 12 53 E | P | WNW, SW | |
| " " | 14 | 40 55 S | 22 25 | 40 35 S | 15 26 | 9 00 E | P | W to WNW | By azimuth of sun when due west true |
| " " | 16 | 38 16 S | 20 06 | 38 03 S | 12 57 | 5 48 E | P | NWxW | By azimuth of sun at 5h 02m & 5h 50m |
| Nightingale Island, Tristan da Cunha | 17 | 37 25 S | 19 20[a] | 37 30 S | 12 17 | ..... | | NWxW to NNW | |
| At sea | 18 | 36 44 S | 13 18[a] | 36 36 S | 8 46 | 4 00 E | P | NNW to W | Sun due west at 5h 17m. "Great sea and rolling motion" |
| " " | 19 | 36 13 S | 11 10 | 36 07 S | 6 37 | 2 30 E | P | W to SW | "Sun in clouds." |
| " " | 20 | 36 01 S | 10 00 | | | | A | SW to NNE | Sighting on port indicated by the obliquity of his beams" |
| " " | 23 | 35 53 S | 5 22[a] | 35 49 S | 1 13 | 0 30W | P | NNE to NNW | |
| " " | Mar. 1 | 26 46 S | 1 32 | 26 30 S | 358 05 | 3 30W | P | SSE to E | |
| " " | 3 | 23 30 S | 1 45 | 23 15 S | 358 24 | 4 10W | P | SE to E | By azimuth of sun at 5h 30m & 5h 50m. "Observed with much difficulty" |
| " " | 5 | 20 25 S | 2 19 | 19 55 S | 359 10 | 4 06W | P | SE | |
| " " | 6 | 18 26 S | 2 53 | | | | P | SE to ExS | |
| " " | 7 | 16 40 S | 3 23 | 17 33 S | 359 55 | 3 30W | A | ExS & SExE | |
| " " | 8 | 16 01 S | 4 23 | | | | P | SxE to ESE | |
| " " | 9 | 15 55 S | 5 54 | 15 58 S | 2 00 | 2 50W | A | SxE to E | |
| " " | 9 | 15 55 S | 5 54 | | | | P | SxE to E | "Well taken" |
| " " | 10 | 15 54 S | 7 07 | 15 55 S | 3 25 | 2 30W | A | SxE to E | |
| " " | 10 | 15 54 S | 7 07 | 15 54 S | 4 17 | 2 00W | P | SxE to E | |

[a] "Believed to be 3° too much."

[b] Allowing for the assumed error of 3° in the longitude of Tristan da Cunha.

[c] Halley remarks: "No Variation 11½° to the Eastward of the Islands." [About 1° 06′ W. of Greenwich, corrected.]

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TABLE II.—*Continued.*

| Place | Date (old style) | Halley's noon position | | Corr'd position for place of observation | | Magnetic Declination | Sun's amplitude, A. or P. M. | Wind | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | Lat. | Long. W. of London | Lat. | Long. W. of Greenwich | | | | |
| | 1700 | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | | | |
| St. Helena | Mar. 12 | 15 52 S | 8 40[6] | 15 55 S | 5 42 | ..... | ..... | ..... | No "variation" ashore given |
| At sea | 31 | 16 18 S | 7 30 | 16 27 S | 7 07 | 1 00W | P | E to ENE | "By a good amplitude" |
| " " | Apr. 2 | 17 21 S | 10 56 | 17 31 S | 10 58 | 0 00 | P | ExN to SExS | |
| " " | 3 | 18 00 S | 12 54 | 18 08 S | 13 08 | 1 00 E | P | SExS to SExE | |
| " " | 4 | 18 34 S | 15 00 | 18 45 S | 15 24 | 2 00 E | P | SxE to ExS | |
| " " | 5 | 19 18 S | 17 00 | 19 07 S | 16 39 | 2½ E | A | ExS to ENE | |
| " " | 7 | 20 13 S | 20 10 | 20 07 S | 20 11 | *3 30* E | A | SExS to ESE | |
| " " | 9 | 20 24 S | 22 26 | 20 24 S | 22 51 | *4 24* E | A | ExN | |
| " " | 10 | 20 23 S | 23 37 | 20 23 S | 24 10 | *4 30* E | A | ExN, ENE | |
| " " | 10 | 20 23 S | 23 37 | 20 24 S | 25 24 | *5 00* E | P | ExN, ENE | |
| " " | 11 | 20 25 S | 25 20[7] | | | | A | ENE | |
| " " | 11 | 20 25 S | 25 20 | 20 25 S | 26 36 | *5 06* E | P | ENE | |
| " " | 13 | 20 21 S | 26 38 | 20 22 S | 27 55 | *6 25* E | A | Various | |
| Trinidad | 15-19 | 20 27 S | 27 50[8] | 20 30 S | 29 30 | 6 30 E | ..... | ..... | "By several good observations" |
| At sea | 21 | 18 49 S | 30 33 | 18 23 S | 30 21 | 6 27 E | P | E, ENE | |
| " " | 22 | 17 05 S | 30 55 | 16 37 S | 30 46 | 5 36 E | P | ExN | |
| " " | 23 | 15 14 S | 31 19 | 15 42 S | 31 01 | 5 51 E | A | E, ExS | |
| " " | 24 | 13 54 S | 31 41 | 13 28 S | 31 36 | 5 04 E | P | ENE | |
| " " | 25 | 12 10 S | 32 00 | 12 36 S | 31 47 | 5 31 E | A | ExS | |
| " " | 26 | 10 18 S | 32 20 | 9 54 S | 32 26 | 5 15 E | P | SSE | |
| Pernambuco | May 1 | 8 10 S | 35 30[9] | 8 03 S | 34 55 | 4 38 E | A | ..... | |
| At sea | 5 | 6 25 S | 35 00 | 6 25 S | 35 01 | *4 00* E | A&P | SExS to E | |
| " " | 6 | 4 32 S | 35 21 | 3 45 S | 36 49 | *4 30* E | P | ESE to SE | |
| " " | 7 | 2 58 S | 36 28 | | | | A | SExE, ESE | |
| " " | 8 | 2 04 S | 37 36 | 1 49 S | 39 55 | *4 05* E | P | ESE, SExE | "Accurately" |
| " " | 9 | 1 04 S | 39 01 | 0 48 S | 41 54 | *5 00* E | P | SExE to E | "Not so certainly as last night" |
| " " | 10 | 0 00 | 40 17 | 0 00 | 43 18 | *5 08* E | A&P | ExS, ExN to NE | "Both well taken." "Dark, cloudy weather" |
| " " | 11 | 1 37N | 40 54[10] | ..... | ..... | ..... | ..... | ExS to NE | |
| " " | 15 | 7 11N | 46 56[11] | 7 29N | 50 27 | *4 53* E | P | ENE to NE | |
| " " | 16 | 8 25N | 50 17[12] | 8 25N | 51 28 | *4 45* E | A&P | NE | |
| " " | 17 | 9 27N | 51 38[12] | 9 49N | 53 21 | *4 48* E | P | ENE to NE | "The current now sets wholly West" |
| Bridgetown, Barbados | 21 | ..... | 57 57[13] | 13 04N | 59 37 | ..... | ..... | E to SE | |
| Bridgetown, Barbados | 22 | ..... | 59 05 | 13 04N | 59 37 | 5 25 E | P | E to SE | |
| Bridgetown, Barbados | 23 | ..... | 59 05 | 13 04N | 59 37 | *5 21* E | A | E to SE | "Allowing for change in Sun's azimuth from his rising to his appearance over the land" |
| Anguilla | June 6 | 18 20N | 62 50 | 18 10N | 63 15 | ..... | ..... | ..... | Halley's position from first voyage |
| At sea | 10 | 18 30N | 63 00 | 18 48N | 63 31 | 4 27 E | P | ENE | |
| " " | 12 | 22 13N | 63 46 | 22 13N | 64 16 | 4 36 E | A | ENE, ExS | |
| " " | 13 | 23 50N | 63 59 | 24 16N | 64 35 | 3 35 E | P | ExS | |
| | | | | | | 3 17 E | P | | |

[6] Longitude "is 2° more than by Coelestial Observation I have found it formerly."

[7] Longitude = 27° 20′ by occultation of star by the Moon, but correction not applied until arrival at Trinidad.

[8] Longitude = 29° 50′ using observation of April 11.

[9] Source of the longitude not given, but Halley's reckoning from Trinidad would make it about 34° 55′, or correct.

[10] Longitude = 43° 45′ "allowing for current setting NWxW along shore at the rate of 30′ per diem."

[11] Longitude = 48° 56′, "I allow Current to have set 2° 00′ since the 11th day to the Westward."

[12] Allowing 30′ per day set to westwards on May 16, 17, 18, 19 and 20.

[13] Longitude is still over 1° in error, after allowing 7½° for current; "And we have been set full 10 Leagues a day to the Westwards in this whole course."

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TABLE II.—*Continued.*

| Place | Date (old style) | Halley's noon position | | Corr'd position for place of observation | | Magnetic Declination | Sun's amplitude A. or P. M. | Wind | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | Lat. | Long. W. of London | Lat. | Long. W. of Greenwich | | | | |
| | 1700 | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | | | |
| At sea | June 14 | 25 35N | 64 11 | 25 35N | 64 47 | 2 25 E<br>2 16 E | A<br>P | ESE to SSE | |
| " " | 15 | 26 50N | 64 21 | 26 50N | 65 00 | 1 40 E<br>1 30 E | A<br>P | SSE | |
| " " | 16 | 28 02N | 64 33 | 28 19N | 65 18 | 1 17 E | P | SSE | |
| " " | 17 | 29 10N | 64 47 | 29 10N | 65 31 | 1 07 E<br>1 02 E | A<br>P | SSE | |
| " " | 18 | 30 05N | 64 30 | 30 05N | 65 17 | 0 52 E<br>0 14 E | A<br>P | SE, ExN | |
| " " | 19 | 31 03N | 64 30 | 31 03N | 65 19 | 0 22 E<br>0 02W | A<br>P | ENE | |
| " " | 20 | 31 56N | 64 00 | 32 03N | 64 48 | 0 09W | P | ESE, E | |
| St. George's Island, Bermuda | 21 | 32 24N | 63 45[14] | 32 23N | 64 40 | ..... | ..... | ..... | |
| At sea | July 12 | 32 59N | 63 37 | 32 59N | 64 28 | 1 10W<br>1 20W | A<br>P | ..... | |
| " " | 17 | 38 36N | 67 20 | 38 30N | 67 23 | 6 00W | P | NE, NExE | |
| " " | 18 | 38 10N | 66 05 | 38 24N | 66 24 | 6 00W | P | NxE to NE | |
| " " | 19 | 39 08N | 66 20 | 38 54N | 66 24 | 5½ W | A | ENE to E | |
| " " | 21 | 41 00N | 64 45 | 41 07N | 64 27 | 7 45W | P | NW, NNW, WSW | "By azimuth of sun and moon" |
| " " | 22 | 41 28N | 63 41 | 41 27N | 63 30 | *8 26*W | P | WSW to S | |
| " " | 23 | 41 24N | 63 32 | 41 28N | 63 06 | *8 50*W | P | Calm to ENE & NE | "Sea rippling and breaking in a fearful manner" |
| " " | 24 | 41 40N | 62 44 | 41 40N | 62 25 | *8 52*W | A&P | WNW to SWxS | |
| " " | 26 | 43 22N | 59 27 | 43 07N | 59 23 | 9 30W | A | SW to NNW | |
| " " | 28 | 43 37N | 57 32 | 43 48N | 56 42 | *10 36*W | P | N to NW | "Well taken" |
| " " | 29 | 44 22N | 56 58 | 44 22N | 56 10 | *11 15*W | A&P | Calm to WNW | |
| " " | 30 | 45 56N | 55 23 | 45 56N | 54 30 | *13 30*W | A&P | W to WSW | |
| Toad's Cove, Newfoundland | Aug. 5 | ..... | 54 00[15] | 47 13N | 52 50 | 15 00W | A | Westerly | "And so much I found it as [illegible] my needles" |
| At sea | 7 | 47 00N | 53 20 | 47 26N | 50 42 | 14 40W | P | NE & NExN | |
| " " | 8 | 47 52N | 50 20 | | | | A | SxE to WSW | |
| " " | 17 | 50 16N | 28 00 | 50 18N | 26 36 | 9 10W | P | W to S | "By azimuth of Moon" |
| " " | 19 | 50 08N | 23 30 | 50 00N | 21 47 | 8 15W | P | S to SW | "By two good azimuths" |
| " " | 21 | 49 25N | 17 17 | 49 21N | 16 19 | 7 32W | P | WxS, NE to NExN | "By a good azimuth" |
| " " | 22 | 49 08N | 16 28 | 49 12N | 15 56 | 6 17W | A | NExE to SExE | |
| " " | 26 | 49 49N | 6 53[16] | 49 52N | 5 45 | 7 13W | P | SSW to NW | |
| Off the Eddystone | 27 | ..... | ..... | 50 00N | 4 15 | 6 33W | A | WNW & NW | Position approximate |
| Off Beachy | 31 | 50 42N | ..... | 50 40N | 0 15 | 7 14W | A | Easterly | |

[14] "I made several observations to determine the Longitude of this Island, which I find to agree with my reckoning Account."

[15] "By my account from Bermudas and by my Observation (occultation of star by Moon) of July 29, A. M."

[16] Longitude by bearings = 6° 15′. "West part of St. Agnes Isle bore due North."

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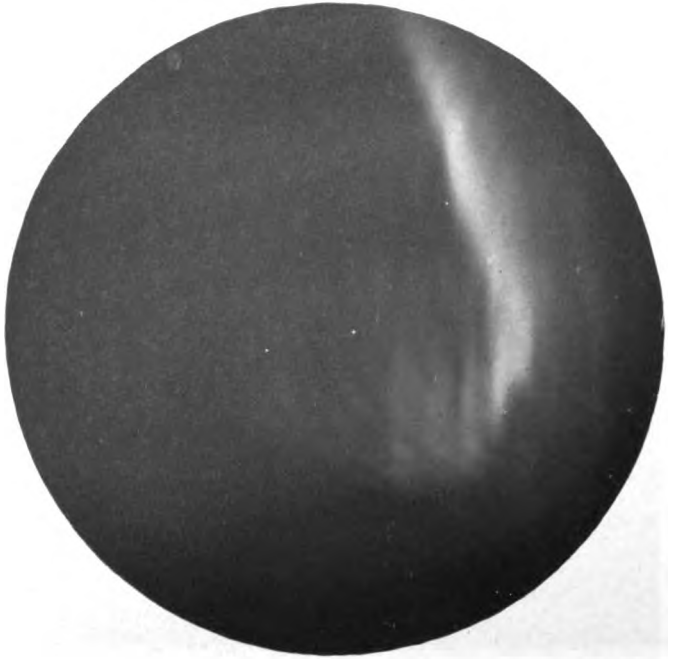
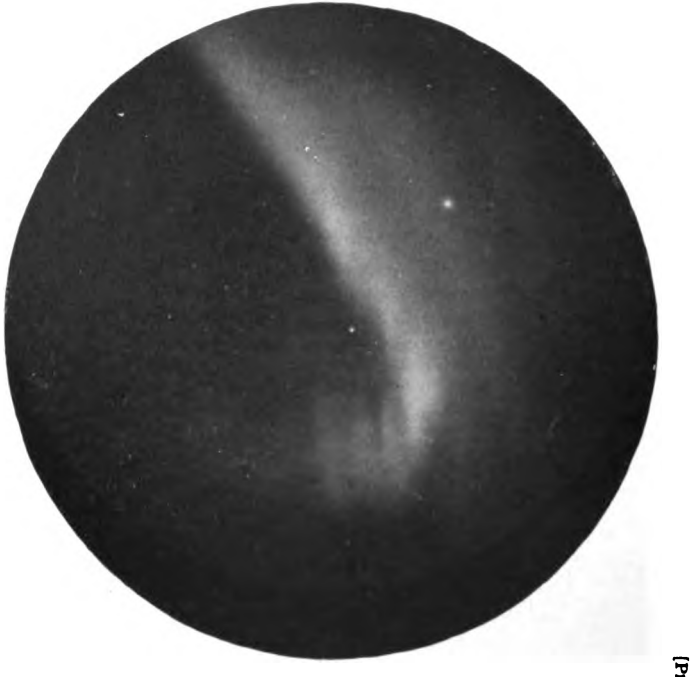


PHOTOGRAPHED FROM STORE KORSNES.



PHOTOGRAPHED FROM BOSSEKOP.

AURORAL DRAPERY WITH DENEB, MARCH 11, 1913, $12^h\ 36^m$.

[PLATE VI.]

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# ON AN AURORAL EXPEDITION TO BOSSEKOP IN THE SPRING OF 1913.

By Professor Carl Störmer (*Christiania*).

The following is a short account of a new auroral expedition which I made to Bossekop in the spring of 1913 for the purpose of completing the results of my expedition to the same place in 1910.

My assistant was the meteorologist, Bernt Johannes Birkeland, who also went with me in 1910, and is going with Roald Amundsen's expedition across the North Polar basin.

The purpose of the expedition was mainly to obtain more accurate and a greater number of auroral photographs for the determination of the form of the aurora, and its height and situation in space, and further to experiment with prism-objective photographing and the taking of cinematograph films.

Our preparations and equipment were on the whole the same as in 1910[1]; but the following improvements, based upon experience gained on that expedition, were carried out:

The cameras were furnished with an arrangement whereby a photograph of an illuminated watch-face was taken on the plate exactly simultaneously with the aurora. The time could then be read from the photograph, and also the exposure by the sector described by the second-hand. This improvement I had already employed in photographing auroras in Christiania in the winter of 1910-1911.

In order to avoid the waste of time in changing plates in a dark-room, each station, in addition to 40 cassettes, was furnished with changing-boxes in which the plates could be changed in the open air. Thanks to this improvement, it was possible on some evenings to take more than 80 simultaneous photographs at the two stations.

In order to have the arms at liberty, the following improvement in the telephone arrangement was made: The microphone and receiver were fixed to the chest and head, and connected with the field telephone apparatus by a cord 4 meters in length. In this

[1]See Bericht über eine Expedition nach Bossekop zwecks photographischer Aufnahmen und Höhenmessungen von Nordlichtern, mit 57 Figuren im Text und 88 Tafeln. Videnskapsselskabets Skrifter, Math-Naturv. Klasse 1911, No. 17, Christiania, 1911.



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way it became possible to utilize more fully the brief moments during which the aurora displayed its greatest intensity.

For the purpose of obtaining reliable parallaxes, a base of 27.5 kilometers was chosen, as against 4.5 kilometers in 1910. The station at which Birkeland took up his quarters was *Store Korsnes*, the other was *Bossekop*. As assistant at Bossekop I had engaged Sergeant Ottem. The direction from Bossekop to Korsnes was almost due north.

Through the courtesy of the Telegraph Department, the State telephone-line from Bossekop to Korsnes was placed at our disposal every night from 7.30 P. M.

Thanks to these arrangements, we succeeded in one month in taking the following pairs of simultaneous auroral photographs at Bossekop and Korsnes:

| Day 1913 | Number of Pairs Taken | Number of Pairs Successful |
|---|---|---|
| Feb. 28 | 14 | 0 |
| March 3 | 38 | 19 |
| " 4 | 23 | 9 |
| " 6 | 7 | 1 |
| " 11 | 86 | 58 |
| " 14 | 81 | 54 |
| " 15 | 81 | 72 |
| " 16 | 8 | 2 |
| " 17 | 14 | 7 |
| " 18 | 5 | 5 |
| " 21 | 23 | 20 |
| " 22 | 20 | 12 |
| " 23 | 1 | 1 |
| " 24 | 6 | 6 |
| " 28 | 5 | 3 |
| " 29 | 83 | 64 |
| " 30 | 71 | 62 |
| April 1 | 70 | 52 |
| Total | 636 | 447 |

On the six best evenings, the 11th, 14th, 15th, 29th, and 30th of March, and 1st of April, the weather was clear and the aurora vivid and continuous, so that we were able to make use of every chance.

The parallaxes, thanks to the large base, were very distinct, as a rule between 5 and 15 degrees, and the large number of photographs—447 pairs as against 44 in 1910—gives very much more certain and complete results than on that occasion. If we reckon about 10 measurements to each photograph, these will give more than 4,000 reliable determinations of height. All important forms

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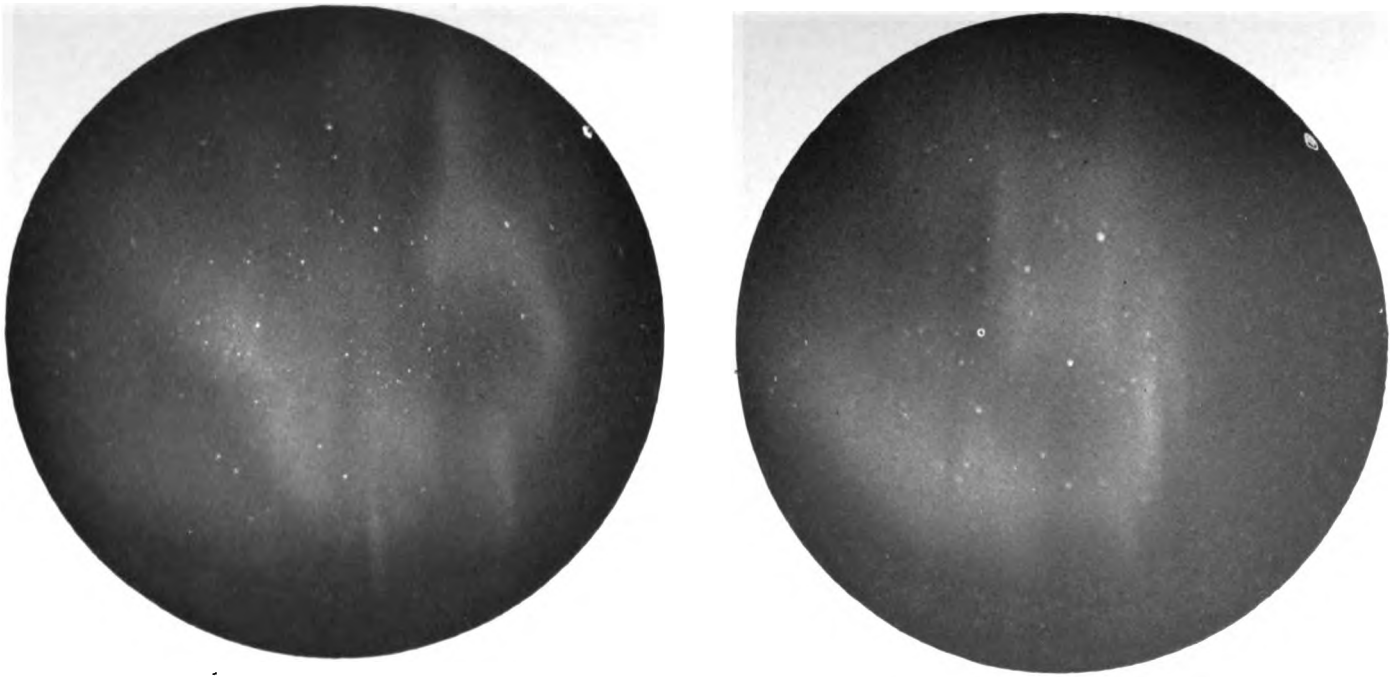
[PLATE VII.]



PHOTOGRAPHED FROM STORE KORSNES. PHOTOGRAPHED FROM BOSSEKOP.

AURORA WITH DENEB, MARCH 14, 1913, $13^h$ $52^m$.

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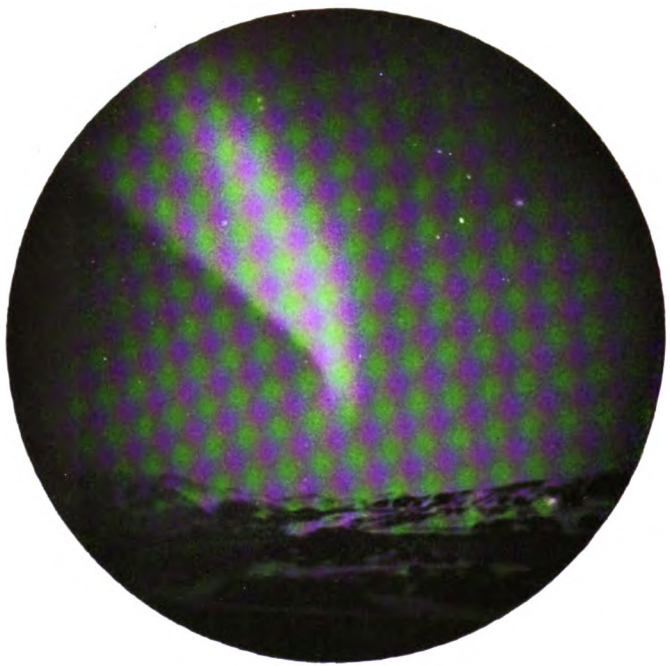
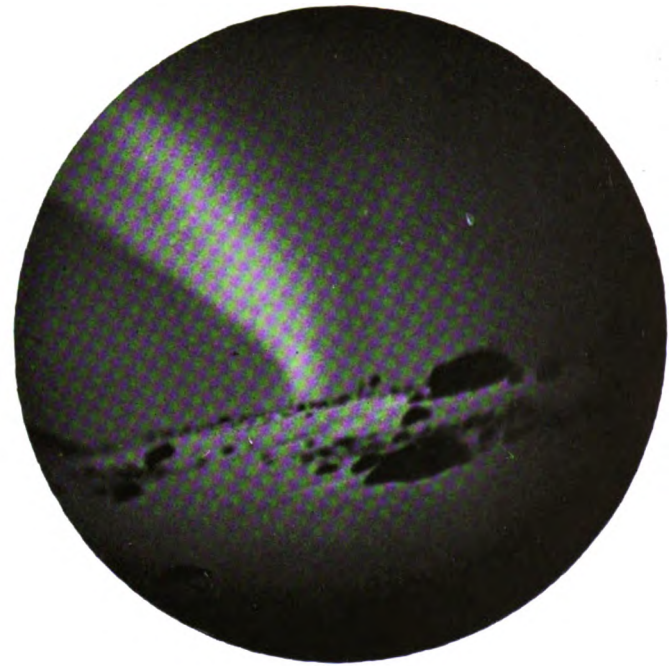


PHOTOGRAPHED FROM STORE KORSNES.



PHOTOGRAPHED FROM BOSSEKOP.

AURORAL ARC WITH GEMMA, MARCH 15, 1913, $8^h$ $13^m$.

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of aurora were photographed, and there are long series of developments.

Some of the photographs are here reproduced (Plates IV, V, VI), enlarged about 2¼ times, one degree answering to 2 mm. in the photograph. The time is Central European time and reckoned from $0^h$ to $24^h$, $0^h$ answering to 12 noon.

With a prism-objective we succeeded in taking some photographs simultaneously with the auroral photographs, on which are seen stellar spectra and all views of the aurora lying side by side, answering to various spectral lines. The prism[2] had an angle of 60° and was placed in front of the kinostigmatic objective, on the principle already mentioned in my "Bericht."[1] A systematic employment of this method will be of great importance to the study of the highest strata of the atmosphere.

Most of the cinematograph attempts were failures, as the film (Lumiére) was not as a rule affected by an exposure of less than 2 seconds. It was only with very intense auroras that we succeeded in getting good photographs with an exposure of about 1 second and with about 2 seconds' interval between the photographs. Two or three such series were taken, thus proving the utility of the cinematograph both for taking photographs and for registering rapid changes.

The working-up of the matter collected during the expedition will be the subject of a subsequent detailed account.

[2]With regard to the kind of glass that would be best for the purpose, I received valuable information from Dr. *Slipher* when visiting the Flagstaff Observatory in the summer of 1912.

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# BIOGRAPHICAL SKETCH OF WILLIAM SUTHERLAND, M. A., B. Sc.

By E. F. J. Love.

The late Mr. William Sutherland, an exceptionally brilliant speculative physicist, was born at Glasgow, on August 4th, 1859; brought by his parents to Australia in 1864, he was educated at Wesley College, Melbourne, then at the Melbourne University, and subsequently at University College, London.

He commenced his career as an investigator in 1885, and during the succeeding twenty-six years published no less than sixty-four papers. As illustrating the versatility of his genius, the following may be quoted from the list: the Mechanical Integration of the Product of Two Functions; the Laws of Molecular Force, the Electric Origin of Rigidity, Gravitation and Terrestrial Magnetism, the Chemistry of Globulin, and Bode's Law. But there is not the slightest doubt that it is on his long series of memoirs, mostly theoretical, dealing with the Molecular Theory of Matter, that his fame will ultimately rest. That all his hypotheses will be accepted, even in their final forms, is unlikely, but his discussions of them are of permanent value.

Mr. Sutherland must be credited with, at least, one discovery of the first rank, viz.: the exact relation between gaseous viscosity and temperature, now well known as "Sutherland's Law." Of scarcely less interest is his discovery of the degree and character of the molecular association in water at different temperatures; the important results obtained by him in this respect have been somewhat unaccountably overlooked by later workers. To our readers he is, perhaps, best known from his ingenious, if but partially successful, attempt to account for the Earth's magnetism by the rotation with the Earth of its internal electric charges.

Mr. Sutherland was of a singularly modest and retiring, but withal most amiable disposition. He took little part in public affairs, save that, on two occasions, he assisted in the teaching of physics in the Melbourne University, during the absence of the professor. He died very suddenly, on October 5th, 1911, deeply regretted by all who had the pleasure of knowing him.[1]

[1] The Editor regrets that it has not been possible to procure for reproduction a photograph of Mr. Sutherland taken after boyhood.



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# RESULTS OF MAGNETIC OBSERVATIONS MADE BY THE UNITED STATES COAST AND GEODETIC SURVEY AT THE TIME OF THE SOLAR ECLIPSE OF OCTOBER 10, 1912.

By O. H. Tittmann, *Superintendent.*

These results were obtained in response to a circular letter received from the Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington requesting cooperation in magnetic and allied observations at the time of the solar eclipse of October 10, 1912.

The magnetic observers in charge of the observatories were directed to exercise especial care to have the magnetographs in good working order on October 10, and for several days before and after that date.

The observatories are all supplied with magnetographs of the Eschenhagen type. The instrument rooms are well insulated and the daily range of temperature is so small that the effect of change of temperature on the magnets during the period of the eclipse can therefore be neglected.

The locations of the observatories and the necessary data regarding the variometers are as follows:

*Location of magnetic observatories.*

| Station | State | Lat. | Long. | Observer-in-charge |
|---|---|---|---|---|
| | | ° ′ | ° ′ | |
| Vieques, | Porto Rico, | 18 08.8 | 65 26.9 | C. F. Woodyard |
| Cheltenham, | Maryland, | 38 44.0 | 76 50.5 | George Hartnell |
| Tucson, | Arizona, | 32 14.8 | 110 50.1 | A. F. Beal |
| Sitka, | Alaska, | 57 03.0 | 135 20.1 | F. L. Adams |
| Honolulu, | Hawaii, | 21 19.2 | 158 03.8 | J. W. Green |

*Magnetic elements and scale values.*

| Observatory | Approximate Magnetic Elements | | | Scale Values of Mag'graphs | | |
|---|---|---|---|---|---|---|
| | *D* | *H* | *Z* | *D* | *H* | *Z* |
| | ° ′ | γ | γ | ′ | γ | γ |
| Porto Rico, | 2 42W | 28630 | 34350 | 1.0 | 4.75 | 3.92 |
| Cheltenham, | 5 51W | 19680 | 56070 | 1.0 | 2.36 | 5.39 |
| Tucson, | 13 34 E | 27310 | 46100 | 1.0 | 2.75 | 3.82 |
| Sitka, | 30 22 E | 15620 | 56210 | 1.0 | 4.43 | 5.50 |
| Honolulu, | 9 36 E | 29115 | 24115 | 1.0 | 2.41 | 2.84 |



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In the following tables (Nos. I, II, and III) are given the values of the declination ($D$), horizontal intensity ($H$), and vertical intensity ($Z$) for each five minutes Greenwich mean time from $11^h$ to $16^h$ on October 10, based on the photographic records of the magnetographs. The ordinates were read from the magnetograms in such manner that each tabular result is approximately the average value for the five-minute period of which the tabular time is in the middle.

Tables IV to VI contain the normal diurnal variation of $D$, $H$ and $Z$ for October, based upon a few selected quiet days throughout the month.

The curves shown in the illustrations are the graphical reproductions of the numerical data given in the tabulations of the magnetic elements. The curves marked *Dm*, *Hm*, and *Zm* show the normal diurnal variation of $D$, $H$ and $Z$ during the month of October; the curves marked $D$, $H$, and $Z$ show the variation of those elements on October 10, 1912, from 11 hours to 16 hours Greenwich civil mean time, which covers the period of the eclipse at the observatories, Porto Rico, however, being the only one within any part of the shadow. The vertical hachured lines on the Porto Rico curves show the approximate time of beginning and ending of the eclipse at that station. The arrows on the diagrams point to easterly motion in declination and to increasing horizontal and vertical intensity.

*United States Coast and Geodetic Survey,*
*Washington, D. C.*

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TABLE I.

*Declination, October 10, 1912.*

| G. M. T. | Vieques | Cheltenham | Tucson | Sitka | Honolulu |
|---|---|---|---|---|---|
| h m | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| 11 00 | 2 41.1W | 5 49.9W | 13 34.5 E | 30 21.8 E | 9 35.4 E |
| 05 | 41.0 | 49.8 | 34.5 | 21.8 | 35.4 |
| 10 | 41.0 | 49.8 | 34.5 | 21.4 | 35.4 |
| 15 | 40.8 | 49.8 | 34.5 | 21.2 | 35.4 |
| 20 | 40.7 | 49.7 | 34.5 | 21.1 | 35.3 |
| 25 | 40.7 | 49.0 | 34.6 | 21.1 | 35.4 |
| 30 | 40.7 | 49.0 | 34.6 | 21.6 | 35.4 |
| 35 | 40.6 | 48.9 | 34.6 | 22.0 | 35.4 |
| 40 | 40.6 | 48.9 | 34.6 | 22.1 | 35.5 |
| 45 | 40.5 | 48.9 | 34.6 | 22.1 | 35.6 |
| 50 | 40.4 | 48.8 | 34.7 | 22.1 | 35.6 |
| 55 | 40.4 | 48.8 | 34.7 | 22.1 | 35.6 |
| 12 00 | 40.4 | 48.8 | 34.7 | 22.1 | 35.6 |
| 05 | 40.1 | 48.8 | 34.7 | 22.1 | 35.6 |
| 10 | 39.9 | 48.9 | 34.6 | 22.1 | 35.6 |
| 15 | 39.8 | 48.3 | 34.5 | 21.8 | 35.6 |
| 20 | 39.8 | 47.8 | 34.6 | 21.4 | 35.5 |
| 25 | 39.9 | 47.8 | 34.8 | 21.6 | 35.6 |
| 30 | 39.9 | 48.4 | 35.1 | 22.4 | 35.7 |
| 35 | 39.8 | 48.5 | 35.1 | 22.8 | 35.7 |
| 40 | 39.8 | 48.3 | 35.1 | 22.6 | 35.8 |
| 45 | 39.8 | 48.1 | 35.1 | 22.4 | 35.7 |
| 50 | 39.8 | 47.9 | 35.2 | 22.3 | 35.7 |
| 55 | 39.7 | 47.8 | 35.2 | 22.4 | 35.7 |
| 13 00 | 39.7 | 47.8 | 35.3 | 22.6 | 35.7 |
| 05 | 39.7 | 47.8 | 35.4 | 22.4 | 35.7 |
| 10 | 39.7 | 47.8 | 35.4 | 22.6 | 35.7 |
| 15 | 39.7 | 47.7 | 35.5 | 22.7 | 35.7 |
| 20 | 39.8 | 47.5 | 35.6 | 22.7 | 35.8 |
| 25 | 39.8 | 47.7 | 35.6 | 22.8 | 35.8 |
| 30 | 39.8 | 47.8 | 35.7 | 22.9 | 35.8 |
| 35 | 39.8 | 47.8 | 35.7 | 22.6 | 35.9 |
| 40 | 39.8 | 47.8 | 35.7 | 22.2 | 35.9 |
| 45 | 39.8 | 47.8 | 36.0 | 21.7 | 35.9 |
| 50 | 39.8 | 47.8 | 36.3 | 21.5 | 35.9 |
| 55 | 39.9 | 47.8 | 36.4 | 21.8 | 35.9 |
| 14 00 | 39.9 | 47.8 | 36.4 | 21.8 | 36.0 |
| 05 | 39.9 | 47.8 | 36.4 | 21.9 | 36.0 |
| 10 | 39.9 | 47.8 | 36.5 | 22.0 | 36.0 |
| 15 | 40.0 | 47.9 | 36.5 | 22.0 | 36.0 |
| 20 | 40.1 | 47.8 | 36.6 | 22.3 | 36.0 |
| 25 | 40.2 | 47.8 | 36.7 | 22.6 | 36.0 |
| 30 | 40.4 | 48.0 | 36.6 | 22.9 | 36.0 |
| 35 | 40.5 | 48.1 | 36.6 | 23.0 | 36.0 |
| 40 | 40.6 | 48.4 | 36.6 | 22.9 | 36.0 |
| 45 | 40.7 | 48.5 | 36.5 | 22.5 | 36.0 |
| 50 | 40.7 | 48.7 | 36.5 | 22.2 | 36.0 |
| 55 | 40.7 | 48.8 | 36.5 | 22.3 | 36.0 |
| 15 00 | 40.8 | 48.8 | 36.5 | 22.4 | 36.0 |
| 05 | 40.8 | 48.9 | 36.5 | 22.7 | 36.0 |
| 10 | 40.9 | 49.0 | 36.5 | 23.0 | 36.1 |
| 15 | 41.0 | 49.1 | 36.5 | 23.2 | 36.1 |
| 20 | 41.1 | 49.6 | 36.4 | 23.3 | 36.1 |
| 25 | 41.3 | 49.7 | 36.4 | 23.4 | 36.1 |
| 30 | 41.5 | 49.8 | 36.4 | 23.2 | 36.1 |
| 35 | 41.7 | 49.8 | 36.4 | 22.8 | 36.1 |
| 40 | 41.7 | 49.9 | 36.4 | 22.7 | 36.1 |
| 45 | 41.7 | 50.2 | 36.4 | 22.9 | 36.1 |
| 50 | 41.7 | 50.6 | 36.3 | 23.6 | 36.2 |
| 55 | 41.8 | 50.8 | 36.2 | 24.1 | 36.3 |
| 16 00 | 41.8 | 50.9 | 35.9 | 24.4 | 36.3 |



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TABLE II.

*Horizontal Intensity, October 10, 1912.*

| G. M. T. | Vieques | Cheltenham | Tucson | Sitka | Honolulu |
|---|---|---|---|---|---|
| h m | γ | γ | γ | γ | γ |
| 11 00 | 28625 | 19684 | 27320 | 15623 | 29111 |
| 05 | 25 | 83 | 20 | 23 | 11 |
| 10 | 26 | 83 | 20 | 24 | 12 |
| 15 | 27 | 84 | 21 | 25 | 13 |
| 20 | 27 | 83 | 22 | 27 | 13 |
| 25 | 28 | 83 | 21 | 27 | 13 |
| 30 | 29 | 83 | 21 | 27 | 12 |
| 35 | 29 | 83 | 21 | 27 | 12 |
| 40 | 29 | 82 | 21 | 27 | 12 |
| 45 | 29 | 81 | 21 | 27 | 13 |
| 50 | 30 | 81 | 21 | 27 | 12 |
| 55 | 30 | 81 | 21 | 27 | 12 |
| 12 00 | 30 | 80 | 21 | 27 | 12 |
| 05 | 31 | 79 | 20 | 27 | 13 |
| 10 | 32 | 78 | 21 | 27 | 14 |
| 15 | 33 | 77 | 22 | 28 | 14 |
| 20 | 34 | 76 | 21 | 28 | 14 |
| 25 | 35 | 76 | 21 | 27 | 14 |
| 30 | 35 | 77 | 22 | 27 | 14 |
| 35 | 35 | 76 | 22 | 27 | 14 |
| 40 | 36 | 74 | 21 | 27 | 13 |
| 45 | 36 | 74 | 21 | 27 | 14 |
| 50 | 37 | 72 | 21 | 27 | 14 |
| 55 | 37 | 71 | 21 | 27 | 14 |
| 13 00 | 37 | 70 | 21 | 27 | 14 |
| 05 | 38 | 69 | 21 | 27 | 14 |
| 10 | 38 | 68 | 21 | 28 | 14 |
| 15 | 37 | 67 | 21 | 28 | 14 |
| 20 | 35 | 65 | 21 | 27 | 14 |
| 25 | 35 | 64 | 20 | 27 | 14 |
| 30 | 35 | 63 | 19 | 27 | 14 |
| 35 | 35 | 61 | 19 | 27 | 14 |
| 40 | 35 | 60 | 19 | 27 | 15 |
| 45 | 34 | 59 | 18 | 25 | 16 |
| 50 | 34 | 58 | 17 | 24 | 16 |
| 55 | 34 | 57 | 17 | 24 | 16 |
| 14 00 | 33 | 57 | 16 | 24 | 16 |
| 05 | 33 | 55 | 16 | 24 | 16 |
| 10 | 32 | 54 | 16 | 25 | 16 |
| 15 | 32 | 53 | 15 | 27 | 16 |
| 20 | 31 | 54 | 14 | 27 | 15 |
| 25 | 31 | 52 | 14 | 27 | 15 |
| 30 | 30 | 52 | 13 | 26 | 14 |
| 35 | 30 | 52 | 12 | 26 | 14 |
| 40 | 29 | 52 | 11 | 25 | 14 |
| 45 | 29 | 51 | 11 | 25 | 14 |
| 50 | 29 | 52 | 11 | 26 | 14 |
| 55 | 29 | 51 | 10 | 26 | 14 |
| 15 00 | 27 | 50 | 09 | 24 | 14 |
| 05 | 27 | 50 | 08 | 22 | 14 |
| 10 | 27 | 51 | 08 | 23 | 14 |
| 15 | 26 | 51 | 08 | 23 | 14 |
| 20 | 26 | 51 | 07 | 23 | 14 |
| 25 | 26 | 52 | 07 | 23 | 14 |
| 30 | 26 | 53 | 06 | 23 | 14 |
| 35 | 27 | 53 | 04 | 22 | 14 |
| 40 | 27 | 53 | 03 | 22 | 14 |
| 45 | 27 | 53 | 02 | 22 | 14 |
| 50 | 26 | 53 | 02 | 22 | 13 |
| 55 | 26 | 53 | 01 | 23 | 13 |
| 16 00 | 26 | 53 | 01 | 23 | 13 |



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TABLE III.

*Vertical Intensity, October 10, 1912.*

| G. M. T. | Vieques | Cheltenham | Tucson | Sitka | Honolulu |
|---|---|---|---|---|---|
| h m | γ | γ | γ | γ | γ |
| 11 00 | 34360 | 56069 | 46109 | 56214 | 24120 |
| 05 | 60 | 69 | 09 | 15 | 20 |
| 10 | 59 | 69 | 09 | 16 | 20 |
| 15 | 58 | 69 | 09 | 18 | 20 |
| 20 | 57 | 69 | 09 | 18 | 20 |
| 25 | 57 | 70 | 09 | 18 | 20 |
| 30 | 57 | 70 | 09 | 17 | 20 |
| 35 | 56 | 70 | 09 | 17 | 20 |
| 40 | 56 | 70 | 09 | 17 | 20 |
| 45 | 55 | 70 | 09 | 17 | 20 |
| 50 | 54 | 69 | 09 | 18 | 20 |
| 55 | 54 | 69 | 09 | 18 | 20 |
| 12 00 | 54 | 70 | 09 | 18 | 20 |
| 05 | 54 | 70 | 09 | 18 | 20 |
| 10 | 54 | 70 | 09 | 18 | 20 |
| 15 | 53 | 70 | 09 | 18 | 20 |
| 20 | 53 | 70 | 09 | 19 | 19 |
| 25 | 53 | 71 | 09 | 18 | 19 |
| 30 | 53 | 71 | 09 | 17 | 19 |
| 35 | 53 | 71 | 09 | 16 | 20 |
| 40 | 53 | 70 | 09 | 16 | 19 |
| 45 | 53 | 71 | 09 | 17 | 19 |
| 50 | 52 | 71 | 10 | 17 | 19 |
| 55 | 52 | 70 | 10 | 17 | 19 |
| 13 00 | 51 | 70 | 10 | 17 | 19 |
| 05 | 51 | 71 | 10 | 17 | 19 |
| 10 | 50 | 70 | 10 | 17 | 19 |
| 15 | 50 | 70 | 10 | 17 | 19 |
| 20 | 49 | 70 | 11 | 17 | 19 |
| 25 | 49 | 70 | 11 | 16 | 19 |
| 30 | 49 | 70 | 11 | 16 | 19 |
| 35 | 47 | 69 | 12 | 16 | 19 |
| 40 | 46 | 69 | 12 | 16 | 19 |
| 45 | 46 | 69 | 12 | 18 | 19 |
| 50 | 46 | 69 | 12 | 18 | 19 |
| 55 | 45 | 68 | 12 | 17 | 19 |
| 14 00 | 45 | 67 | 12 | 16 | 19 |
| 05 | 45 | 66 | 12 | 15 | 19 |
| 10 | 45 | 65 | 12 | 14 | 19 |
| 15 | 45 | 64 | 12 | 14 | 19 |
| 20 | 45 | 64 | 12 | 14 | 19 |
| 25 | 45 | 64 | 12 | 14 | 19 |
| 30 | 45 | 63 | 11 | 14 | 19 |
| 35 | 45 | 62 | 11 | 14 | 19 |
| 40 | 45 | 62 | 11 | 14 | 19 |
| 45 | 45 | 61 | 11 | 14 | 18 |
| 50 | 46 | 61 | 11 | 15 | 18 |
| 55 | 46 | 60 | 11 | 15 | 18 |
| 15 00 | 46 | 59 | 11 | 14 | 18 |
| 05 | 46 | 59 | 11 | 14 | 18 |
| 10 | 46 | 59 | 11 | 14 | 19 |
| 15 | 46 | 59 | 11 | 14 | 19 |
| 20 | 46 | 59 | 11 | 14 | 19 |
| 25 | 47 | 58 | 11 | 14 | 19 |
| 30 | 47 | 58 | 12 | 14 | 19 |
| 35 | 49 | 57 | 12 | 15 | 19 |
| 40 | 49 | 56 | 12 | 15 | 18 |
| 45 | 49 | 56 | 12 | 14 | 19 |
| 50 | 49 | 55 | 12 | 14 | 19 |
| 55 | 49 | 55 | 12 | 13 | 19 |
| 16 00 | 49 | 55 | 12 | 11 | 20 |



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TABLE IV.

*Diurnal variation of declination, October, 1912.*

| L. M. T. | Vieques | Cheltenham | Tucson | Sitka | Honolulu |
|---|---|---|---|---|---|
| h | ′ | ′ | ′ | ′ | ′ |
| 1 | —0.3 | —0.4 | —0.2 | —0.2 | —0.3 |
| 2 | —0.2 | —0.1 | —0.2 | —0.1 | —0.1 |
| 3 | 0.0 | +0.2 | —0.1 | 0.0 | +0.1 |
| 4 | +0.1 | +0.3 | +0.1 | +0.8 | +0.2 |
| 5 | +0.2 | +0.3 | +0.4 | +1.0 | +0.4 |
| 6 | +0.2 | +1.2 | +0.8 | +1.5 | +0.7 |
| 7 | +0.8 | +2.2 | +2.0 | +2.4 | +1.6 |
| 8 | +1.6 | +3.2 | +2.6 | +3.0 | +2.0 |
| 9 | +2.0 | +2.9 | +2.0 | +2.8 | +1.4 |
| 10 | +1.4 | +1.4 | +0.8 | +2.1 | +0.3 |
| 11 | +0.4 | —0.6 | —0.6 | 0.0 | —0.8 |
| 12 | —0.5 | —2.2 | —1.8 | —1.4 | —1.3 |
| 13 | —1.1 | —2.9 | —1.8 | —2.0 | —1.2 |
| 14 | —1.4 | —2.7 | —1.3 | —1.8 | —0.9 |
| 15 | —1.5 | —1.7 | —0.7 | —1.8 | —0.5 |
| 16 | —1.1 | —0.9 | —0.4 | —1.4 | —0.3 |
| 17 | —0.8 | —0.3 | —0.4 | —1.1 | —0.2 |
| 18 | —0.3 | —0.1 | —0.3 | —0.6 | —0.1 |
| 19 | 0.0 | 0.0 | —0.2 | —0.6 | 0.0 |
| 20 | +0.2 | +0.2 | —0.2 | —0.6 | 0.0 |
| 21 | +0.2 | +0.2 | —0.1 | —0.6 | —0.1 |
| 22 | +0.1 | 0.0 | —0.1 | —0.6 | —0.2 |
| 23 | 0.0 | 0.0 | —0.2 | —0.6 | —0.3 |
| 24 | —0.2 | —0.2 | —0.2 | —0.3 | —0.3 |

TABLE V.

*Diurnal variation of horizontal intensity, October, 1912.*

| L. M. T. | Vieques | Cheltenham | Tucson | Sitka | Honolulu |
|---|---|---|---|---|---|
| h | γ | γ | γ | γ | γ |
| 1 | 0 | + 4 | + 1 | + 5 | — 3 |
| 2 | 0 | + 5 | + 4 | + 6 | — 3 |
| 3 | — 1 | + 5 | + 4 | + 8 | — 2 |
| 4 | — 1 | + 5 | + 5 | + 6 | — 2 |
| 5 | 0 | + 6 | + 6 | + 7 | — 2 |
| 6 | + 3 | + 5 | + 6 | + 5 | — 1 |
| 7 | + 6 | + 3 | + 2 | + 3 | — 2 |
| 8 | +10 | — 5 | — 4 | — 1 | — 4 |
| 9 | +10 | —12 | — 9 | — 7 | — 2 |
| 10 | + 7 | —16 | —10 | —13 | + 2 |
| 11 | + 6 | —20 | —10 | —13 | + 8 |
| 12 | + 5 | —17 | — 8 | —10 | +11 |
| 13 | 0 | — 9 | — 3 | — 6 | +10 |
| 14 | — 4 | — 3 | + 2 | — 3 | + 6 |
| 15 | — 9 | + 2 | + 4 | — 2 | + 3 |
| 16 | — 9 | + 6 | + 5 | — 2 | + 1 |
| 17 | —13 | + 9 | + 3 | 0 | 0 |
| 18 | — 9 | + 8 | + 1 | + 1 | — 2 |
| 19 | — 5 | + 6 | — 1 | + 4 | — 3 |
| 20 | — 1 | + 4 | — 1 | + 3 | — 3 |
| 21 | + 1 | + 2 | — 2 | + 2 | — 3 |
| 22 | + 2 | + 3 | — 1 | + 2 | — 3 |
| 23 | + 2 | + 4 | 0 | + 2 | — 3 |
| 24 | + 1 | + 4 | + 1 | + 3 | — 3 |



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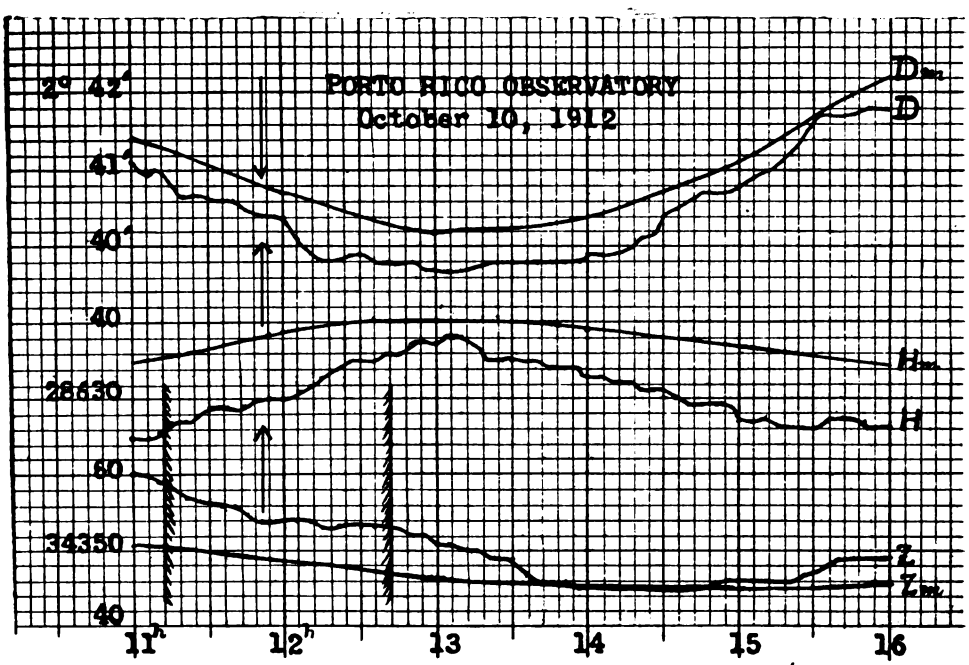
TABLE VI.

*Diurnal variation of vertical intensity, October, 1912.*

| L. M. T. | Vieques | Cheltenham | Tucson | Sitka | Honolulu |
|---|---|---|---|---|---|
| h | γ | γ | γ | γ | γ |
| 1 | 0 | 0 | + 1 | — 2 | + 3 |
| 2 | 0 | 0 | + 1 | — 1 | + 4 |
| 3 | + 1 | 0 | + 1 | — 2 | + 4 |
| 4 | + 2 | 0 | + 2 | — 3 | + 4 |
| 5 | + 3 | 0 | + 2 | — 6 | + 5 |
| 6 | + 2 | 0 | + 2 | — 3 | + 5 |
| 7 | 0 | + 1 | + 3 | — 2 | + 9 |
| 8 | — 2 | + 1 | 0 | — 2 | + 6 |
| 9 | — 4 | — 2 | — 3 | — 3 | — 1 |
| 10 | — 5 | — 5 | — 4 | — 4 | — 7 |
| 11 | — 5 | — 6 | — 6 | — 3 | —11 |
| 12 | — 4 | — 5 | — 6 | 0 | —11 |
| 13 | — 4 | — 1 | — 5 | + 1 | — 8 |
| 14 | — 2 | + 1 | — 2 | + 2 | — 6 |
| 15 | 0 | + 3 | 0 | + 3 | — 4 |
| 16 | + 2 | + 4 | 0 | + 2 | — 3 |
| 17 | + 5 | + 3 | 0 | + 4 | — 2 |
| 18 | + 5 | + 2 | + 1 | + 3 | 0 |
| 19 | + 4 | + 1 | + 1 | + 3 | + 1 |
| 20 | + 2 | 0 | + 2 | + 3 | + 1 |
| 21 | + 1 | 0 | + 2 | + 3 | + 2 |
| 22 | 0 | 0 | + 2 | + 2 | + 2 |
| 23 | — 1 | 0 | + 2 | + 2 | + 3 |
| 24 | — 1 | 0 | + 2 | + 1 | + 3 |



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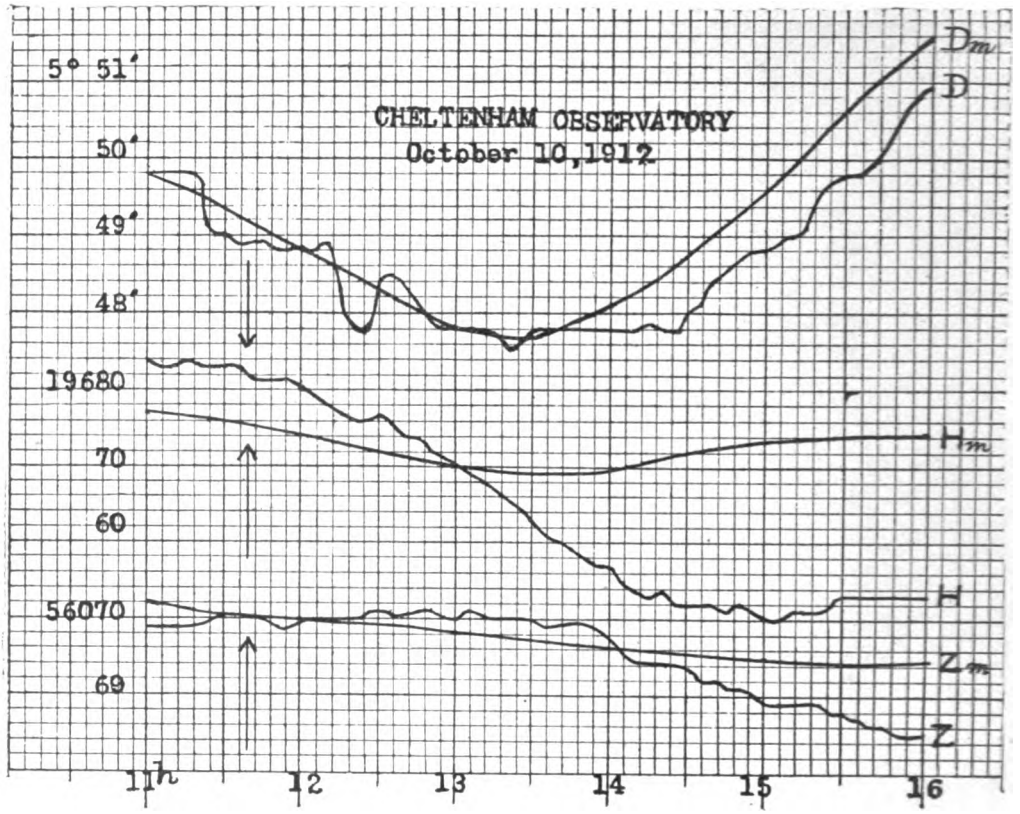


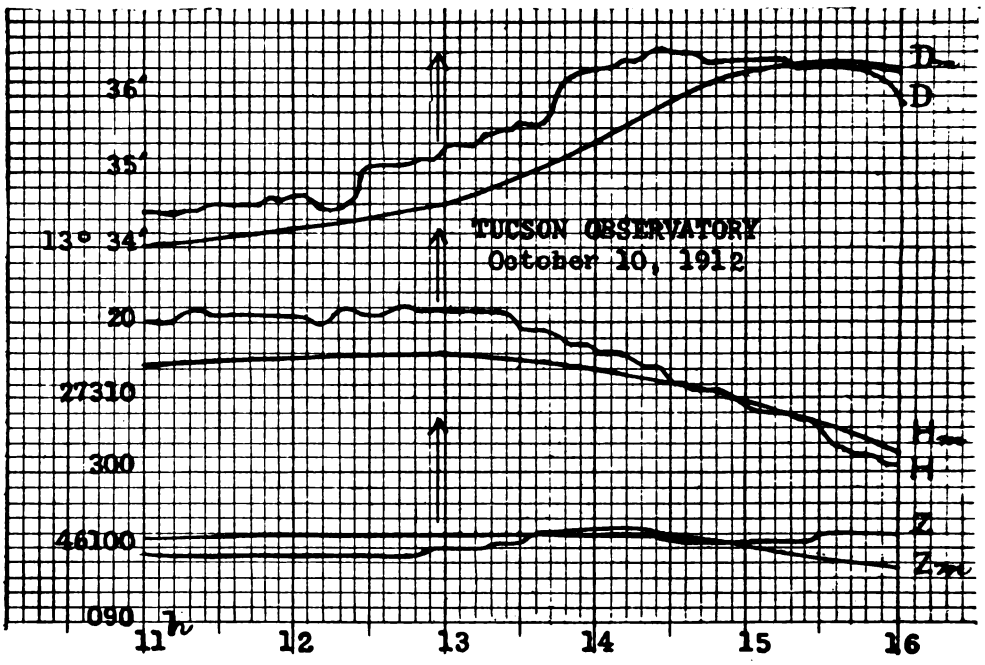




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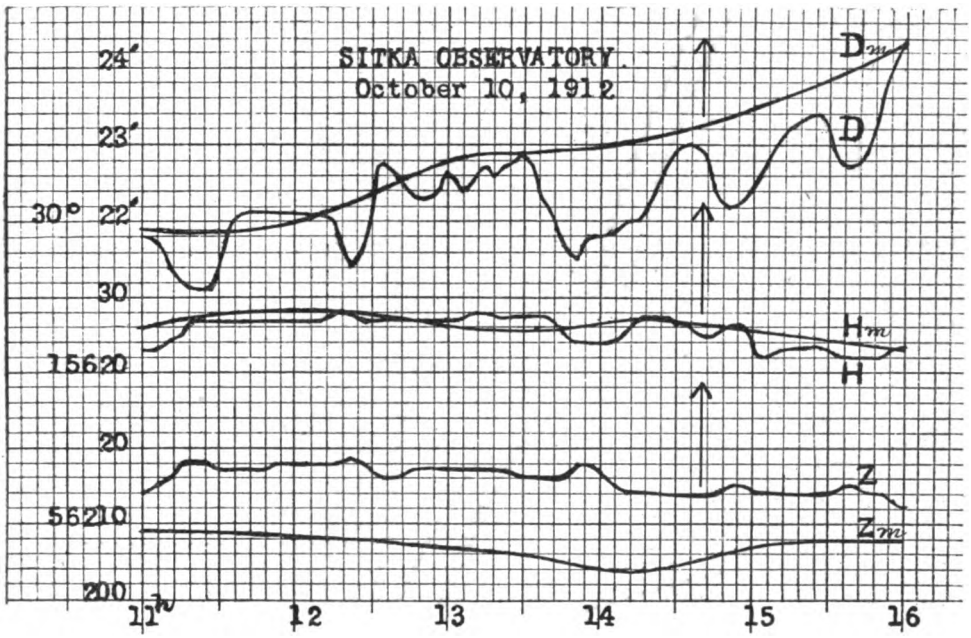


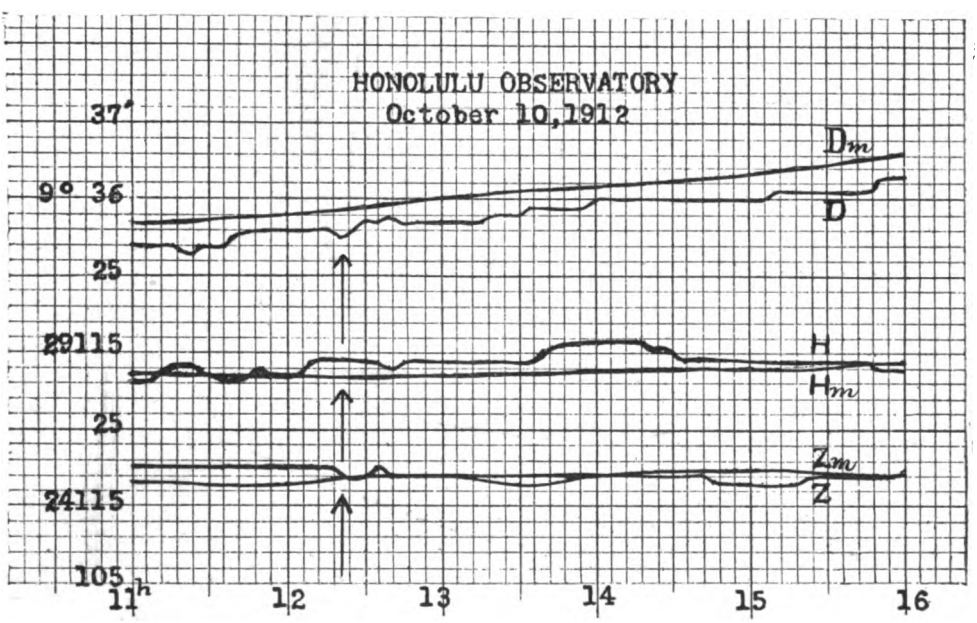




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# *LETTERS TO THE EDITOR*

## PRINCIPAL MAGNETIC STORMS RECORDED AT THE CHELTENHAM MAGNETIC OBSERVATORY.

JANUARY 1 TO JUNE 30, 1913.

*Latitude 38° 44'.0 N; Longitude 76° 50'.5, or 5h 07.4m W. of Greenwich.*

| GREENWICH MEAN TIME | | | | | | RANGE | | |
|---|---|---|---|---|---|---|---|---|
| Beginning | | | Ending | | | D (Declination) | H (Hor'l Int.) | Z (Vert'l Int.) |
| 1913 | h | m | | | h | ′ | γ | γ |
| Jan. 2, | 11 | 14 | Jan. 3, | | 21 | 17.9 | 77 | 33 |
| Jan. 18, | 16 | .. | Jan. 19, | | 24 | 11.0 | 69 | 22 |
| Jan. 29, | 23 | 23 | Jan. 31, | | 4 | 16.8 | 58 | 36 |
| Feb. 14, | 5 | 20 | Feb. 16, | | 3 | 20.0 | 64 | 33 |
| Mar. 14, | 4 | 26 | Mar. 15, | | 12 | 15.7 | 113 | 46 |
| Mar. 16, | 13 | 31 | Mar. 17, | | 9 | 14.8 | 86 | 30 |
| Apr. 8, | 19 | 52 | Apr. 10, | | 11 | 22 | 105 | 76 |
| May 4, | 7 | 51 | May 8, | | 8 | 32 | 91 | 49 |
| June 1, | 6 | 20 | June 2, | | 3 | 24 | 106 | 37 |

GEORGE HARTNELL, *Observer-in-Charge.*

O. H. TITTMANN, *Superintendent,*
*Coast and Geodetic Survey.*

## THE MAGNETIC CHARACTER OF THE YEAR 1912.

The annual review of the "Caractère magnétique de chaque jour" for 1912 has been drawn up in the same manner as for the preceding years. Forty-three observatories contributed to the quarterly reviews; all of them sent complete data. According to a request from the Executive Bureau of the Commission on Terrestrial Magnetism of the International Meteorological Committee, the days, which seem especially suited to a reproduction, have been indicated on the quarterly publications. Table II of the annual review, containing the mean character of each day and of each month, the list of "calm days" and the days recommended for reproduction, are reprinted here.

G. VAN DIJK.



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TABLE SHOWING THE MAGNETIC CHARACTER OF THE YEAR 1912.

| DATES | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 0.7 | 0.0 | 0.1 | 0.3 | 0.7 | 0.3 | 0.3 | 0.3 | 0.4 | 0.5 | 0.8 | 1.1 | 1.2 | 0.6 | 0.0 | 0.0 | 0.8 | 0.7 | 0.4 | 0.5 | 0.2 | 1.0 | 0.3 | 0.5 | 0.1 | 0.0 | 0.1 | 0.5 | 0.1 | 0.3 | 0.1 | 0.42 |
| February | 0.1 | 0.7 | 0.6 | 0.3 | 0.1 | 0.1 | 0.2 | 0.4 | 0.2 | 0.9 | 0.7 | 1.0 | 1.1 | 0.3 | 0.2 | 0.9 | 1.0 | 0.6 | 0.3 | 0.1 | 0.1 | 0.3 | 0.8 | 0.9 | 0.7 | 1.1 | 0.1 | 0.3 | 0.2 | | | 0.49 |
| March | 0.4 | 0.1 | 0.6 | 0.0 | 0.8 | 0.9 | 0.9 | 1.5 | 1.0 | 0.9 | 0.2 | 0.4 | 0.1 | 0.6 | 0.7 | 0.2 | 0.0 | 0.1 | 0.0 | 0.1 | 0.9 | 0.8 | 0.1 | 0.0 | 0.1 | 0.6 | 0.0 | 0.7 | 1.1 | 0.1 | 0.1 | 0.45 |
| April | 0.1 | 0.3 | 0.4 | 0.3 | 1.3 | 1.0 | 0.8 | 0.1 | 0.1 | 1.0 | 0.1 | 0.2 | 0.2 | 0.8 | 1.3 | 1.0 | 1.0 | 0.6 | 0.6 | 0.5 | 0.0 | 0.1 | 0.3 | 0.2 | 0.3 | 0.1 | 0.2 | 0.1 | 0.1 | 0.3 | | 0.45 |
| May | 0.1 | 0.5 | 0.6 | 0.5 | 1.3 | 0.9 | 0.8 | 0.7 | 0.1 | 0.2 | 0.6 | 1.3 | 1.4 | 1.0 | 0.3 | 0.1 | 0.2 | 0.2 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.3 | 0.1 | 0.1 | 0.2 | 0.0 | 0.8 | 0.6 | 0.8 | 0.47 |
| June | 1.0 | 0.8 | 0.8 | 0.2 | 0.0 | 0.1 | 0.6 | 1.2 | 0.9 | 0.9 | 0.6 | 0.3 | 0.1 | 0.2 | 0.1 | 0.1 | 0.3 | 0.2 | 0.1 | 0.1 | 0.2 | 0.6 | 0.9 | 0.6 | 0.2 | 0.2 | 0.8 | 0.9 | 0.8 | 0.3 | | 0.47 |
| July | 0.3 | 0.2 | 0.9 | 1.3 | 1.2 | 0.7 | 0.6 | 0.5 | 0.1 | 0.1 | 0.0 | 0.0 | 0.1 | 0.6 | 0.0 | 0.5 | 0.5 | 0.2 | 0.1 | 0.7 | 0.4 | 0.1 | 0.1 | 0.0 | 0.3 | 0.7 | 0.8 | 0.1 | 0.0 | 0.3 | 1.1 | 0.41 |
| August | 0.9 | 0.3 | 0.2 | 0.0 | 0.9 | 1.7 | 0.5 | 0.0 | 0.0 | 0.3 | 0.2 | 0.0 | 0.0 | 0.5 | 0.4 | 0.4 | 0.9 | 1.0 | 0.9 | 0.2 | 0.6 | 1.1 | 0.9 | 0.4 | 0.3 | 0.1 | 0.8 | 0.7 | 0.4 | 0.3 | 0.3 | 0.49 |
| September | 0.3 | 0.1 | 0.6 | 0.7 | 0.5 | 0.4 | 0.1 | 0.6 | 0 7 | 0.2 | 0.4 | 0.6 | 0.3 | 0.3 | 0.0 | 0.0 | 1.8 | 1.1 | 0.4 | 0.5 | 0.1 | 0.7 | 0.9 | 1.6 | 0.3 | 0.6 | 0.0 | 0.0 | 0.2 | 0.3 | | 0.47 |
| October | 1.0 | 0.0 | 0.6 | 0.3 | 0.0 | 0.1 | 0.4 | 0.3 | 0.2 | 0.4 | 1.2 | 0.8 | 0.9 | 1.6 | 1.3 | 0.9 | 0.7 | 0.0 | 0.0 | 0.7 | 0.3 | 0.4 | 0.3 | 0.2 | 0.3 | 0.0 | 0.3 | 0.7 | 0.1 | 0.2 | 0.1 | 0.46 |
| November | 0.4 | 0.5 | 0.0 | 0.1 | 0.7 | 0.6 | 0.1 | 0.4 | 0.8 | 1.2 | 1.0 | 0.0 | 0.2 | 1.4 | 0.8 | 0.9 | 0.6 | 0.4 | 0.2 | 0.3 | 0.0 | 0.8 | 0.6 | 0.0 | 0.1 | 0.8 | 0.3 | 0.0 | 0.0 | 0.0 | | 0.45 |
| December | 0.3 | 1.0 | 0.7 | 0.0 | 0.0 | 1.0 | 1.4 | 0.6 | 0.5 | 0.2 | 0.4 | 0.1 | 0.8 | 0.4 | 0.1 | 0.0 | 0.0 | 0.3 | 0.1 | 0.0 | 0.0 | 1.2 | 1.3 | 0.9 | 0.5 | 0.2 | 0.0 | 0.0 | 0.2 | 0.5 | 0.1 | 0.43 |



CALM DAYS.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 2, | 15, | 16, | 26, | 27. | February | 5, | 6, | 15, | 20, | 21. | March | 4, | 17, | 18, | 19, | 24. |
| April | 1, | 8, | 11, | 21, | 28. | May | 1, | 16, | 22, | 23, | 26. | June | 5, | 6, | 15, | 19, | 20. |
| July | 10, | 11, | 12, | 15, | 24. | August | 4, | 8, | 12, | 13, | 26. | September | 2, | 15, | 16, | 27, | 28. |
| October | 2, | 5, | 18, | 19, | 31. | November | 3, | 12, | 21, | 29, | 30. | December | 4, | 5, | 20, | 21, | 28. |

DAYS RECOMMENDED FOR REPRODUCTION.

March 8, August 6, September 17, October 14, December 7,

January 13, February 17, April 5, April 15, May 13, July 5, September 24, November 14, December 23.

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# *LETTERS TO THE EDITOR*

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JANUARY 1 TO JUNE 30, 1913.

*Latitude 38° 44'.0 N; Longitude 76° 50'.5, or 5h 07.4m W. of Greenwich.*

| GREENWICH MEAN TIME | | | | | | RANGE | | |
|---|---|---|---|---|---|---|---|---|
| Beginning | | | Ending | | | D (Declination) | H (Hor'l Int.) | Z (Vert'l Int.) |
| 1913 | h | m | | | h | ′ | γ | γ |
| Jan. 2, | 11 | 14 | Jan. 3, | | 21 | 17.9 | 77 | 33 |
| Jan. 18, | 16 | .. | Jan. 19, | | 24 | 11.0 | 69 | 22 |
| Jan. 29, | 23 | 23 | Jan. 31, | | 4 | 16.8 | 58 | 36 |
| Feb. 14, | 5 | 20 | Feb. 16, | | 3 | 20.0 | 64 | 33 |
| Mar. 14, | 4 | 26 | Mar. 15, | | 12 | 15.7 | 113 | 46 |
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| Apr. 8, | 19 | 52 | Apr. 10, | | 11 | 22 | 105 | 76 |
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## THE MAGNETIC CHARACTER OF THE YEAR 1912.

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G. VAN DIJK.



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TABLE SHOWING THE MAGNETIC CHARACTER OF THE YEAR 1912.

| DATES | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 0.7 | 0.0 | 0.1 | 0.3 | 0.7 | 0.3 | 0.3 | 0.3 | 0.4 | 0.5 | 0.8 | 1.1 | 1.2 | 0.6 | 0.0 | 0.0 | 0.8 | 0.7 | 0.4 | 0.5 | 0.2 | 1.0 | 0.3 | 0.5 | 0.1 | 0.0 | 0.1 | 0.5 | 0.1 | 0.3 | 0.1 | 0.42 |
| February | 0.1 | 0.7 | 0.6 | 0.3 | 0.1 | 0.1 | 0.2 | 0.4 | 0.2 | 0.9 | 0.7 | 1.0 | 1.1 | 0.3 | 0.2 | 0.9 | 1.0 | 0.6 | 0.3 | 0.1 | 0.1 | 0.3 | 0.8 | 0.9 | 0.7 | 1.1 | 0.1 | 0.3 | 0.2 | | | 0.49 |
| March | 0.4 | 0.1 | 0.6 | 0.0 | 0.8 | 0.9 | 0.9 | 1.5 | 1.0 | 0.9 | 0.2 | 0.4 | 0.1 | 0.6 | 0.7 | 0.2 | 0.0 | 0.1 | 0.0 | 0.1 | 0.9 | 0.8 | 0.1 | 0.0 | 0.1 | 0.6 | 0.0 | 0.7 | 1.1 | 0.1 | 0.1 | 0.45 |
| April | 0.1 | 0.3 | 0.4 | 0.3 | 1.3 | 1.0 | 0.8 | 0.1 | 0.1 | 1.0 | 0.1 | 0.2 | 0.2 | 0.8 | 1.3 | 1.0 | 1.0 | 0.6 | 0.6 | 0.5 | 0.0 | 0.1 | 0.3 | 0.2 | 0.3 | 0.1 | 0.2 | 0.1 | 0.1 | 0.3 | | 0.45 |
| May | 0.1 | 0.5 | 0.6 | 0.5 | 1.3 | 0.9 | 0.8 | 0.7 | 0.1 | 0.2 | 0.6 | 1.3 | 1.4 | 1.0 | 0.3 | 0.1 | 0.2 | 0.2 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.3 | 0.1 | 0.1 | 0.2 | 0.0 | 0.8 | 0.6 | 0.8 | 0.47 |
| June | 1.0 | 0.8 | 0.8 | 0.2 | 0.0 | 0.1 | 0.6 | 1.2 | 0.9 | 0.9 | 0.6 | 0.3 | 0.1 | 0.2 | 0.1 | 0.1 | 0.3 | 0.2 | 0.1 | 0.1 | 0.2 | 0.6 | 0.9 | 0.6 | 0.2 | 0.2 | 0.8 | 0.9 | 0.8 | 0.3 | | 0.47 |
| July | 0.3 | 0.2 | 0.9 | 1.3 | 1.2 | 0.7 | 0.6 | 0.5 | 0.1 | 0.1 | 0.0 | 0.0 | 0.1 | 0.6 | 0.0 | 0.5 | 0.5 | 0.2 | 0.1 | 0.7 | 0.4 | 0.1 | 0.1 | 0.0 | 0.3 | 0.7 | 0.8 | 0.1 | 0.0 | 0.3 | 1.1 | 0.41 |
| August | 0.9 | 0.3 | 0.2 | 0.0 | 0.9 | 1.7 | 0.5 | 0.0 | 0.0 | 0.3 | 0.2 | 0.0 | 0.0 | 0.5 | 0.4 | 0.4 | 0.9 | 1.0 | 0.9 | 0.2 | 0.6 | 1.1 | 0.9 | 0.4 | 0.3 | 0.1 | 0.8 | 0.7 | 0.4 | 0.3 | 0.3 | 0.49 |
| September | 0.3 | 0.1 | 0.6 | 0.7 | 0.5 | 0.4 | 0.1 | 0.6 | 0.7 | 0.2 | 0.4 | 0.6 | 0.3 | 0.3 | 0.0 | 0.0 | 1.8 | 1.1 | 0.4 | 0.5 | 0.1 | 0.7 | 0.9 | 1.6 | 0.3 | 0.6 | 0.0 | 0.0 | 0.2 | 0.3 | | 0.47 |
| October | 1.0 | 0.0 | 0.6 | 0.3 | 0.0 | 0.1 | 0.4 | 0.3 | 0.2 | 0.4 | 1.2 | 0.8 | 0.9 | 1.6 | 1.3 | 0.9 | 0.7 | 0.0 | 0.0 | 0.7 | 0.3 | 0.4 | 0.3 | 0.2 | 0.3 | 0.0 | 0.3 | 0.7 | 0.1 | 0.2 | 0.1 | 0.46 |
| November | 0.4 | 0.5 | 0.0 | 0.1 | 0.7 | 0.6 | 0.1 | 0.4 | 0.8 | 1.2 | 1.0 | 0.0 | 0.2 | 1.4 | 0.8 | 0.9 | 0.6 | 0.4 | 0.2 | 0.3 | 0.0 | 0.8 | 0.6 | 0.0 | 0.1 | 0.8 | 0.3 | 0.0 | 0.0 | 0.0 | | 0.45 |
| December | 0.3 | 1.0 | 0.7 | 0.0 | 0.0 | 1.0 | 1.4 | 0.6 | 0.5 | 0.2 | 0.4 | 0.1 | 0.8 | 0.4 | 0.1 | 0.0 | 0.0 | 0.3 | 0.1 | 0.0 | 0.0 | 1.2 | 1.3 | 0.9 | 0.5 | 0.2 | 0.0 | 0.0 | 0.2 | 0.5 | 0.1 | 0.43 |

CALM DAYS.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 2, | 15, | 16, | 26, | 27. | February | 5, | 6, | 15, | 20, | 21. | March | 4, | 17, | 18, | 19, | 24. |
| April | 1, | 8, | 11, | 21, | 28. | May | 1, | 16, | 22, | 23, | 26. | June | 5, | 6, | 15, | 19, | 20. |
| July | 10, | 11, | 12, | 15, | 24. | August | 4, | 8, | 12, | 13, | 26. | September | 2, | 15, | 16, | 27, | 28. |
| October | 2, | 5, | 18, | 19, | 31. | November | 3, | 12, | 21, | 29, | 30. | December | 4, | 5, | 20, | 21, | 28. |

DAYS RECOMMENDED FOR REPRODUCTION.

March 8, August 6, September 17, October 14, December 7,

January 13, February 17, April 5, April 15, May 13, July 5, September 24, November 14, December 23.



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# NOTES

6. *Meeting of International Association of Academies, St. Petersburg. May, 1913.* The following resolutions pertaining to terrestrial magnetism were passed: "The Committee announces the close of the work of the Magnetic Commission [Magnetic Survey of a Parallel of Latitude] and, reserving the privilege of returning to the question in a future meeting, agrees to lend its support to the Permanent Magnetic Commission of the International Meteorological Committee." At the request of M. Rykatchew, the Committee, in view of the work of making a magnetic survey of the globe, particularly on the oceans, undertaken by the Carnegie Institution of Washington, resolves that it is of the highest importance that similar work be completed, as soon as possible, in those countries where no surveys exist or where they have been made at epochs relatively distant from those of the Carnegie Institution of Washington.

7. *Corrigenda.* The March, 1913, issue, should be corrected as follows:

P. 4, line 12 from above: read at $B$, instead at $B'$;
P. 10, line 3 from below: in denominator, read $d\alpha$, instead $dt$;
P. 11, equation 1: read sin $(\alpha—\kappa—\lambda)$, instead sin $(\alpha—\kappa—\gamma)$;
P. 13, equations 9 and 10: inside the brace, cos $\gamma$ should read *cos* $\lambda$;
P. 13, equation 11: last parenthesis should read $(P_s + P'_s)$ instead $(P_s + P')$;
P. 15, line 6 from below: read $Q_r = Q_l$, instead $Q = Q_l$;
P. 16, line 1 from above: insert comma after the word used;
P. 16, line 18 from above: read $(Q_r = Q_l)$, instead $(Q_r = Q)$;
P. 17, line 9 from above: read introduced, instead induced;
P. 18, line 4 from above: read $P'_c$, instead $P^1_c$;
P. 18, line 9 from above: read $-\lambda_r$ and to $+\lambda_l$ (subscripts of $\lambda$ omitted);
P. 28, line 20 from above: $I$ should read $I_c$;
P. 36, Table III, column 2: $\epsilon = 10'$, instead $\epsilon = 30'$.

8. *Information regarding magnetic observatories.* The magnetic work at the *Falmouth Observatory,* in continuous operation for about a quarter of a century, had to be discontinued, for lack of funds, on July 1, of this year. The Royal Cornwall Polytechnic Society deserves great credit for maintaining, in spite of comparatively small financial assistance from outside, a magnetic observatory for such a long period in a region of England where but little disturbance from electric car-lines may be feared and which was readily accessible to shipping interests. The meteorological work is to be continued with the co-operation of the London Meteorological Office. The magnetic part



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of the work at the *Wilhelmshaven Marine Observatorium* is to be discontinued. *Prof. J. C. Beattie* writes under date April 4 last, that the construction of the much desired magnetic observatory for *Cape Colony* is "now being taken in hand." A new vertical intensity variometer (Eschenhagen-Toepfer pattern) and an earth-inductor were installed this year at the *Mauritius Magnetic Observatory* in cooperation with the international work of the Department of Terrestrial Magnetism. *Dr. Chree* writes that "The verification of unifilar magnetometers and dip circles, which has hitherto proceeded at the *New Observatory* under the National Physical Laboratory, will continue to be carried on under the Meteorological Office. In future, the fee for the verification of a unifilar magnetometer (with one collimator magnet) and the supply of the usual constants and tables will be £7.10.0. No change is proposed in the fees for the verification of dip circles or separate dip needles." Reproductions of magnetograms of highly disturbed days in 1911 have been received from *Dr. van Everdingen;* these reproductions are a new publication of the Meteorological Institute at De Bilt, which will appear in future annually. For 1911 the days chosen by the observatories at Potsdam and Jekaterinburg are given; for 1912 and following years, the days indicated in the tables of the "Caractère Magnétique de chaque jour" will be given. *Prof. Palazzo* reports that good progress has been made with the proposed establishment of a magnetic observatory at *Tripoli.* In the new magnetic observatory of the *Royal Observatory, Greenwich,* shortly to be erected, provision it made for the continuation of the long series of Greenwich observations of the variations of the magnetic elements on the same site.

9. *Personalia. Prof. Dr. Max Thomas Edelmann,* of the well-known Munich firm bearing his name, died on April 30 in the 68th year of his age. *General M. Rykatchew,* after having served 46 years at the Observatoire Physique Central Nicolas, of which 17 were as Director, has retired from active service. His future address will be: Général M. Rykatchew, membre de l'Académie Impériale des Sciences, Wass. Ostr., Perspective Sredny, No. 34, log. 9, St. Pétersbourg. *Mr. L. F. Richardson,* formerly assistant lecturer in physics at the Municipal School of Technology, Manchester, entered on his new duties as Superintendent of the Geophysical Observatory, Eskdalemuir, about August 1, *Dr. J. A. Harker* having been in temporary charge since *Mr. Walker's* resignation early in the year. *Mr. T. L. Eckersley,* B. A., of Trinity College, Cambridge, has been appointed assistant in magnetic work at the Helwan Observatory, Egypt. *Prof. C. F. Marvin* has been appointed Chief of the United States Weather Bureau in succession to *Prof. Moore. Prof. A. G. McAdie,* formerly in charge of the Weather Bureau office at San Francisco, has resigned in order to assume his new duties as pro-

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fessor of meteorology at Harvard University and director of the Blue Hill Observatory. The Georg Neumayer gold medal was bestowed upon *Dr. L. A. Bauer,* for his researches in terrestrial magnetism, on May 3, in connection with the celebration of the eighty-fifth anniversary of the Berlin Gesellschaft für Erdkunde. The University of Cincinnati, where Dr. Bauer graduated 25 years ago, conferred upon him the degree of doctor of science, *honoris causa,* and the Academia de Sciencias de Portugal elected him a correspondent member. *Messrs. D. W. Berky and H. E. Sawyer,* magnetic observers of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, who successfully completed last May the trans-Saharan expedition, from Algiers to Timbuktoo, are now making magnetic observations at a series of stations along the Niger River extending into Senegal, French Guinea, Liberia, Nigeria, Lagos, and the Congo Free State and thence along the Ivory and Gold Coasts and other African states to the southward. *Mr. Edward Kitts,* for many years Superintendent of the Falmouth Observatory, has retired from active service.

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## TERRESTRIAL ISOMAGNETIC LINES FOR SOUTH AFRICA FOR THE EPOCH JULY 1, 1903.[1]

This paper is an amplification of the discussion by the same author of his observations in South Africa in 1900-1906, published in his *Report of a Magnetic Survey of South Africa* (1909). The latter work treats the results at about 400 stations lying between the southeast coast and a northeast-southwest line passing through latitude 26 degrees South and longitude 24 degrees East. These data were combined in fifteen groups or districts, the mean value being given for the mean position in each case. After resolving the resulting mean values into components along the three rectangular axes (north, west, vertical), the true isomagnetic lines were charted. The author takes these group values and by use of normal equations computes the "terrestrial isomagnetic lines."

The method of treatment is that credited to Mathias (Paris, 1907). The mean station of District XI is chosen as a point of reference. Then for each of the other fourteen stations, $\triangle\phi$ and $\triangle\lambda$ are the geographical co-ordinates, and $\triangle Z$, $\triangle T$, $\triangle X$, $\triangle Y$ are the differences between the magnetic components of any station and the corresponding value at the station of reference. The fourteen equations for each element take the form:

$$\triangle \text{ (mag. elem.)} = a + b\triangle\lambda + c\triangle\phi + d\,(\triangle\lambda)^2 + e\triangle\lambda\triangle\phi + f\,(\triangle\phi)^2,$$

in which the coefficients of the first order are given to the fifth decimal, and those of the second to the seventh. The charts representing the values resulting from this discussion show both the "true" and the "terrestrial" isomagnetic lines, and seem to indicate that the computed values fit reasonably well, although the omission from the charts of the numbers designating the values represented by the various "terrestrial" lines makes a direct comparison difficult.

H. W. FISK.

[1] BEATTIE, J. C. Terrestrial isomagnetic lines for South Africa for the epoch July 1, 1903. Cape Town, Trans. R. Soc. South Africa, v. 2, Pt. 3, 1912 (283–286 with 4 maps and 4 pl.)

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# BEMERKUNGEN ZU EINEM GEWITTER IN SAN CARLOS DE ANCUD.

VON WALTER KNOCHE (*Santiago*).

Am 25.–26. Oktober 1912 rief ein ausserordentlich heftiges Gewitter in San Carlos de Ancud (Hauptstadt der Inselprovinz Chiloé) die grösste Aufregung unter seinen Bewohnern hervor, da Chile in seinen bewohnten Teilen ein ausserordentlich gewitterarmes Land ist. So beobachteten unter 33 meteorologischen Stationen im Jahre 1911, 13 kein, 12 ein, 3 zwei, 2 drei, 2 vier und nur 1 (Santiago) sieben Gewitter und Wetterleuchten (ohne die stillen Entladungen über den Anden zu zählen); hierzu kommt, dass die beobachteten Gewitter, z. B. alle sieben in Santiago, meist sehr unbedeutender Natur waren.

Das Gewitter, welches ausser in Nordchiloé auch in der Provinz LLanquihue beobachtet wurde, ist nun dadurch interessant, dass es im Seminario Conciliar von Ancud mittelst Registrierapparats aufgezeichnet wurde. P. Galceran, der Direktor des Seminars, hatte die Freundlichkeit, uns die Registrierstreifen einzuschicken und eine kurze Beschreibung des Apparats zu liefern. Derselbe besteht aus einem Branlyschen Kohärer; der Kohärerstrom ($\frac{1}{3}V$) schliesst durch ein Relais (mit Klopfer) den Batteriestrom einer Art Morsetelegraph. Die Erdung ist vorzüglich durch Anschluss an den aus Stahlwerk bestehenden Kirchturm erreicht. An diesen ist, gut isoliert, die Antenne von 80 m Länge bis zur Höhe von 40 m geführt. Den Ablauf des Registrierstreifens besorgt ein Uhrwerk, mit der sehr grossen Geschwindigkeit von 3.60 m pro 1 Stunde oder 6 cm pro 1 Minute oder 1 mm in der Sekunde. Bei etwa 5 Entladungen in der Sekunde hört die Auflösungsfähigkeit dieses Apparates für die Entladungen auf, die dann einen ununterbrochenen Streifen bilden. Es kamen stellenweise tatsächlich, derartige zusammenhängende Partieen trotz der schnellen Abwicklung vor, die längste 6 sec andauernd, mit einem Minimum also von 30 Entladungen während dieser Zeit.

Es ist verständlich, dass für viele Fälle die Registrierapparate mit geringem Umlauf (z. B. Richardscher Konstruktion) mit einer Tages- oder gar Wochentrommel von der Grösse der üblichen meteorologischen Registratoren bei weitem nicht ausreichen. Das Gewitter begann nach den Beobachtungen in Ancud,



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Punta Corona (Leuchtturm am Eingang in die Bai) und in Osorno (in kurzer Entfernung nördlich von Lanquihuesee) am 25. Okt. um $9\frac{1}{2}p$, also gleichzeitig, von ersteren Oertlichkeiten im N und NE, von Osorno aus im SE gesehen. Auch die Orte Volcan am Nordufer des Lanquihuesees und Morro de Lobos (Inselleuchtturm an der Ostküste Chiloés) meldeten Gewitter. An allen Stationen herrschte Windstille während des Gewitters, nirgends fiel gleichzeitig Niederschlag, in Punta Corona nur ein kurzer Schauer nach Schluss der Erscheinung (½ mm). Kurz vor dem Gewitter war der Himmel wenig bewölkt; die Bewölkung nahm sehr rasch zu: cu-ni. Die Farbe der Blitze war weisslich, ihre Richtung sowohl vertikal, wie horizontal. Die Zahl der Stationen ist zu gering, um die Bewegungsrichtung festzustellen, doch scheint ein Zug von NE nach SW vorhanden gewesen zu sein. In der Nähe der Kordillere (Volcan) schienen die Entladungen länger anzuhalten als westlich davon.

Nach dem Registrierapparat liegt der Beginn der Entladungen kurz nach 3 *p* am 25. Okt., also 6 bis 7 Stunden vor der visuellen Beobachtung; diese dauern bis 8.45 *a* am 26. Okt., d. h. 6 Stunden über die persönliche Wahrnehmung hinaus. Aus der folgenden

| 1912 | | Viertel-Stunde | | | | Total. |
|---|---|---|---|---|---|---|
| | | 1. | 2. | 3. | 4. | |
| 25. Okt. | 1p- 2p | 0 | 0 | 0 | 0 | 0 |
| | 2p- 3p | 0 | 0 | 0 | 0 | 0 |
| | 3p- 4p | 1 | 9 | 4 | 7 | 21 |
| | 4p- 5p | 8 | 6 | 9 | 27 | 50 |
| | 5p- 6p | 2 | 4 | 14 | 18 | 38 |
| | 6p- 7p | 41 | 31 | 19 | 39 | 130 |
| | 7p- 8p | 31 | 10 | 9 | 23 | 73 |
| | 8p- 9p | 41 | 46 | 10 | 24 | 121 |
| | 9p-10p | 14 | 54 | 37 | 27 | 132 |
| | 10p-11p | 34 | 16 | 6 | 10 | 66 |
| | 11p-Mittn. | 28 | 29 | 63 | 17 | 137 |
| 26. Okt. | Mittn.- 1a | 9 | 12 | 13 | 7 | 41 |
| | 1a- 2a | 17 | 19 | 39 | 64 | 139 |
| | 2a- 3a | 94 | 59 | 92 | 71 | 316 |
| | 3a- 4a | 135 | 202 | 96 | 108 | 541 |
| | 4a- 5a | 244 | 60 | 117 | 109 | 523 |
| | 5a- 6a | 117 | 121 | 92 | 53 | 383 |
| | 6a- 7a | 61 | 71 | 48 | 29 | 209 |
| | 7a- 8a | 33 | 11 | 7 | 4 | 55 |
| | 8a- 9a | 20 | 12 | 5 | 0 | 37 |
| | 9a-10a | 0 | 0 | 0 | 0 | 0 |
| | 10a-11a | 0 | 0 | 0 | 0 | 0 |

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Tabelle, welche die Entladungszahlen pro Viertelstunden (und Stunden) gibt, ist aber deutlich erkennbar, dass das Maximum der Blitze erst nach dem Verschwinden des Gewitters für den Beobachter ($2\frac{1}{2}a$), zwischen $3a$ und $5a$ (244 Entladungen zwischen $4a$ und $4\frac{1}{4}a$, d. h. über 16 pro Minute) erreicht wird. Unter grossen Schwankungen der Entladungszahlen im einzelnen nahmen diese (Combination von je 2 Stunden) vom Beginn bis $6p$ ziemlich langsam zu, blieben bis Mitternacht konstant, stiegen rapide bis $4a$ an, nahmen ebenso rapide bis $8a$ und dann langsam bis zum Erlöschen ab.

Die Gesamtzahl der aufgezeichneten Entladungen überschreitet 3000. Diese Zahl spiegelt sich wider in den Berichten der Beobachter, die von zeitweise unzählbaren Blitzen bei ohrenbetäubendem Donner sprechen, einem Schauspiel, wie es seit "Menschengedenken" nicht beobachtet wurde. Die Blitze schlugen zahlreich unter Verzweigungen ins Meer; Flächenblitze scheinen, abgesehen von oscillatorischen Entladungen, auch in der Nahperiode, vorhanden gewesen zu sein, so dass die Zahl der Aufzeichnungen vielleicht noch zu gering ist. Es wurde schon erwähnt, wie wenig zahlreich die Gewitter allenthalben in Chile sind. Um so mehr muss es überraschen, wenn der Registrator des Seminars in Ancud an allen Tagen der mir vorliegenden Oktoberbeobachtungen Hertzsche Wellen aufgezeichnet hat.

| 1912 | 8a-8a | 1912 | 8a-8a | 1912 | 8a-8a |
|---|---|---|---|---|---|
| 11. Okt.[1] | 495 | 18. Okt. | 192 | 25. Okt. | 36 |
| 12. | 72 | 19. | 5 | 26. | 3012 |
| 13. | 61 | 20. | 64 | 27. | 418 |
| 14. | 28 | 21. | 54 | 28. | 64 |
| 15. | 126 | 22. | 36 | 29. | 220 |
| 16. | 209 | 23. | 58 | 30. | 270 |
| 17. | 711 | 24. | 26 | 31. | 136 |

Aufnahmen von funkentelegraphischen Zeichen kommen bei der Unempfindlichkeit des Gewitterregistrators und dem Mangel kräftiger *RT*-Stationen in der Gegend kaum in Frage.

Es scheint sich hiernach, da den Sitz dieser Entladungen weder die Inselwelt, noch das Meer oder die nördliche Seenregion bildet, um Gewitter zu handeln, die sich innerhalb der Kordillere abspielen.

[1] Aufstellung d. Apparats am 10. Okt.; eine detailliertere Bearbeitung der Originalstreifen soll demnächst erfolgen.



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Die Beobachtungen der Stationen Osorno, Punta Corona, Ancud, Morro de Lobos scheinen dafür zu sprechen, dass auch das beschriebene Gewitter aus der Cordillera real, vielleicht aus der Vulkanregion östlich vom Llanquihuesee in ziemlich breiter Flanke (gleichzeitiger Beginn in Osorno und Ancud) heraustrat, sich nach NW bis zur Erreichung des Nordendes von Chiloé bewegte, um dann langsam nach S oder SW (Beobachtung in Morro de Lobos) zu ziehen; wahrscheinlicher noch ist es, an eine sich vorschiebende und wieder zurückziehende Randpartie eines in der Kordillere gelegenen Entladungszentrums zu denken (Diskordanz zwischen dem Verschwinden des Gewitters in Ancud und dem erst nachfolgenden Häufigkeitsmaximum der Notierungen), früheres Erlöschen in Ancud und Punta Corona als in den der Kordillere näheren Morro de Lobos und Volcan.

Da die meteorologischen Aufzeichnungen gar keine Veranlassung zu der betrachteten elektrischen Störung erkennen lassen, so ist eine Beziehung zu vulkanischen Ausbrüchen oder Exhalationen (Ionenbildung) nicht ausgeschlossen, zumal tätige Vulkane (Vulkan Osorno, Calbuco u. a.) in der betreffenden Region nicht fehlen. Vielleicht sind auch die täglich registrierten Wellen zur vulkanischen Tätigkeit in Beziehung zu setzen. Nicht unerwähnt soll bleiben, dass der Leuchtturmwärter und meteorologische Beobachter in Punta Corona angibt, vor Ausbruch des Gewitters unterirdische Geräusche und Zittern des Bodens bemerkt zu haben. Auch für die stillen Entladungen, die in der Meteorologischen Zeitschrift mehrmals von mir beschieben wurden, scheint sich herauszustellen, dass sie ihre Zentren nicht selten in den Vulkanen haben, eine Meinung übrigens, die der verstorbene, in meteorologischen Beobachtungen so erfahrene Dr. Martin in Puerto Montt (vor allem in Bezug auf den Vulkan Calbuco am LLanquihuesee) energisch vertreten hat.[2]

Es sei an dieser Stelle nun die Mitteilung gestattet, dass auch zumindestens im mittleren (wahrscheinlich auch nördlichen) Chile, die Gewitter in der Cordillere durchaus nicht selten zu sein scheinen. Die bekannte Gewitterarmut des langgestreckten Westküstenlandes ist eine Folge der Unbewohnbarkeit und Unzugänglichkeit eines grossen Teiles seines Areals, also eine scheinbare, sie besteht in Wahrheit nur für das Längstal resp. die Hochebene und Küste. Im Sommer (für den Winter fehlen Berichte völlig) haben Touristen

[2] Ich erfuhr diese interessante Anschauung vor kurzem durch einen Bekannten des Herrn Dr. Martin. S. auch M. Z. 2. S. 88, 1912.

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und Mineningenieure das Vorhandensein zahlreicher kräftigen Gewitter zumeist bei gleichzeitigem Graupelfall in den grösseren Höhen der Anden festgestellt; sie finden mitunter fast täglich statt, scheinen ihr Maximum am Nachmittag zu haben und gewisse Oertlichkeiten (geschlossene Täler, cajones) zu bevorzugen, an anderen fast nie aufzutreten. Die vom Längstal aus gesehenen schweren cu-ni und cu-ca-Wolken, die nachmittags ihre grösste Entwicklung erreichen, um abends zu verschwinden, sind also wohl als Sitze dieser elektrischen Erscheinungen zu betrachten. Es ist schwer zu sagen, ob die Differenzierung der Entladungen in disruptive bei Vorhandensein von Bewölkung und stille bei Wolkenlosigkeit in eben diesem Umstande eine ihrer Ursachen hat.

Erwähnenswert ist ferner eine Behauptung der zeitweiligen Kordillerenbewohner, wie Offizieren des Korps der Carabineros, Beamten der Minen u. a., dass in gewissen (abgeschlossenen) Tälern nach Dynamitschüssen während der Nachmittagsstunden unweigerlich ein Gewitter mit Niederschlägen folge, während anderenfalls das Wetter unverändert bliebe.

Dieses Phänomen, das im Gegensatz zu dem problematischen Hagelschiessen steht, ist sorgsam nachzuprüfen; bei der guten Beobachtungsgabe der in Frage kommenden Bevölkerungsklasse halte ich aber seine Realität für sehr wahrscheinlich.

Auf jeden Fall birgt die *Cordillera real* noch viele Probleme, deren Lösung bei der Schwierigkeit des Zutritts nicht immer leicht, schliesslich aber doch wohl möglich sein wird.

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## *ABSTRACTS AND REVIEWS*

### MACKOWER'S AND GEIGER'S PRACTICAL MEASUREMENTS IN RADIO-ACTIVITY.[1]

The need of a proper guide for a practical course in radio-active measurements is at last supplied, and this little book, emanating as it does from one of the chief centers (Manchester) of radio-active investigation, will doubtless receive a warm reception. The work is intended not only as an introductory course for students intending to undertake original investigations in radio-activity, but also for those already engaged in such work. The authors have been very successful in showing that a practical course in radio-active measurements can be prosecuted with a small layout for radio-active materials.

Many of the experiments described are selections from those forming the course of practical work in the Honours School of Physics in the Manchester

[1] London, Longmans, Green & Co., 1912 (IX + 151 with 61 figs.) 22 cm.

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University. All of the experiments are simple and direct, and relate to the most fundamental principles of radio-activity. The theory of each experiment is briefly and concisely stated, and the discussions are remarkably free from unnecessary details, which in so many laboratory manuals often obscure the main issue. A good deal of space is given to the actual technique involved in the manipulation of the instruments, thus saving the experimenter a large amount of time which would otherwise be spent in acquiring this technique by experience. One undertaking this work alone will be especially benefited by this feature of the work.

Two very useful appendices are given which contain a table of radio-active constants and various other tables and decay data for radio-active substances.

*Aboard the Carnegie, June 18, 1913.* C. W. HEWLETT.

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## THE TENTH EDITION OF MÜLLER-POUILLET'S PHYSICS. (Vol. IV, Part 2.)[1]

The advance in electrical science and engineering in a quarter-century is strikingly seen on comparing the present volume with the corresponding one of the ninth edition, which appeared in 1888-1890. The editors have performed their difficult task well; and yet, whenever a new edition of any comprehensive work in physics appears, one feels a keen regret that so often historical matter and accounts of pioneer discoveries are crowded out. More than one experimenter in recent years has regarded as "new" an observation which, had he consulted an old edition of Wiedemann or of Winkelmann's "Handbuch," he would have found described in detail.

In the book before us are Chapters VIII to XI on electricity and magnetism. In general, the comments made in the review of the first part of Vol. IV apply here also. References to the literature as late as 1911 are given.

Chapter VIII is on Electromagnetism and Electrodynamics. The ground is in the main very fully covered, though we look in vain for a reference to Joseph Henry's electro-magnets. The treatment of telegraphy is hardly adequate. A good account is given of the modern theory of magnetism, but nothing is said about the temperature coefficient of the magnetic moment.

Chapter IX, Induced Currents, contains *inter alia* some excellent paragraphs on the induction coil and on modern interrupters. On p. 807 we note that $\delta W$ is printed by mistake instead of $\delta w$.

Chapter X, Direct-Current Engineering, includes a very brief treatment of electric lighting, but does not mention Cooper Hewitt.

Chapter XI is subdivided into three parts. At several points Part A, Alternating Currents, seems rather inadequate, especially with reference to magnetic leakage, high-frequency generators, converters, and motors.

Parts B and C are on Electric Oscillations and Wireless Telegraphy, respectively. Seven pages contained all that there was to say on these subjects in 1890! The part on oscillations is greatly to be recommended on account of

[1] MÜLLER-POUILLET'S Lehrbuch der Physik und Meteorologie, 10th edition, revised and enlarged, in four volumes. Edited by LEOP. PFAUNDLER, Professor of Physics at the University of Graz. Fourth Volume, Second Part, Magnetism and Electricity, pp. vii + 353, by WALTER KAUFMANN and ALFRED COEHN. Braunschweig, Vieweg, 1912. (For reviews of the earlier volumes see this Journal for December, 1907, p. 185; March, 1908, p. 42; and March, 1910, p. 42.)

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its clear exposition and good descriptions of experiments. The treatment of wireless telegraphy, though brief, is fairly up-to-date.

The remaining chapters on electricity and magnetism, including atmospheric electricity and terrestrial magnetism, are still to appear. W. G. CADY.

*Wesleyan University, Middletown, Connecticut.*

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H. BENNDORF: *Über die Beobachtungen der Niederschlagselektrizität.*[1]

This paper is a discussion of the observations of the electrical state of precipitation, both rain and snow, which have been made as follows: (1) Elster and Geitel, at Wolfenbüttel, (a) 1888-1889, (b) 1890-1893; (2) Gerdien, at Göttingen, 1902; (3) Weisz, at Wien, 1906; (4) Kohlrausch, at Porto Rico, 1907-1908; (5) Simpson, at Simla, (a) 1908, (b) 1909; (6) Kähler, at Potsdam, 1908; (7) Benndorf, at Graz, (a) 1908-1909, (b) 1909-1910; and (8) Baldit, at Puy-en-Velay, (a) 1910, (b) 1911.

While different forms of apparatus and various methods were employed by the several investigators, the results have been rendered comparable by means of reducing all to the same terms. These include (1) the area of the collecting area in square centimeters, (2) the capacity of the collecting instrument in cubic centimeters, (3) the ratio of the capacity of the gauge to the area of the collecting surface, (4) the smallest measurable quantity of electrification, (5) the vertical current through the atmosphere in amperes per square centimeter, (6) the time interval during which the measurements were made, and (8) the maximum value of the current measured.

The author points out the difficulties to be encountered and the dangers to be avoided in investigations of this nature. Because of the great variety of conditions under which the observations were made, especially of climate and of latitude, but few general conclusions can be drawn. However, the more obvious conclusions are as follows:

(1) In general, observations extending over a considerable period of time show a distinct predominance of cases of a positive charge in descending rain or snow, that is, negative charges were in the minority. At Simla the precipitations (rain) measured were found to be positively charged in 75 per cent of the first series and in 78 per cent of the second series of cases; at Puy-en-Velay the proportion was 58 per cent, and at Graz 72 per cent of the cases. Moreover, positively charged rain continued to fall longer than that carrying the opposite charge. At Simla positively charged rain fell during (a) 70 per cent and (b) 73 per cent of the time the measurements were in progress; at Puy-en-Velay the proportion was (a) 60 per cent and (b) 74 per cent, and at Graz 75 per cent of the time.

(2) At Simla and Puy-en-Velay it was found that when the charge carried by the precipitation was very feeble the potential was more frequently negative, and when the charge was relatively strong the potential was more often positive. Moreover, negatively charged precipitation was usually weak in its electrification, while that of the opposite charge was more often strong. At Graz the results were slightly different. Here very weak and very strong charges were usually negative, while only moderate charges were more frequently positive. At all the 8 stations noted the charges carried by precipitation were weak in a large majority of the cases.

[1] Repr. München, Sitz Ber. Ak. Wiss., 1912 (402–429 with 1 pl.). Bericht Nr. 1.

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University. All of the experiments are simple and direct, and relate to the most fundamental principles of radio-activity. The theory of each experiment is briefly and concisely stated, and the discussions are remarkably free from unnecessary details, which in so many laboratory manuals often obscure the main issue. A good deal of space is given to the actual technique involved in the manipulation of the instruments, thus saving the experimenter a large amount of time which would otherwise be spent in acquiring this technique by experience. One undertaking this work alone will be especially benefited by this feature of the work.

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H. BENNDORF: *Über die Beobachtungen der Niederschlagselektrizität.*[1]

This paper is a discussion of the observations of the electrical state of precipitation, both rain and snow, which have been made as follows: (1) Elster and Geitel, at Wolfenbüttel, (a) 1888-1889, (b) 1890-1893; (2) Gerdien, at Göttingen, 1902; (3) Weisz, at Wien, 1906; (4) Kohlrausch, at Porto Rico, 1907-1908; (5) Simpson, at Simla, (a) 1908, (b) 1909; (6) Kähler, at Potsdam, 1908; (7) Benndorf, at Graz, (a) 1908-1909, (b) 1909-1910; and (8) Baldit, at Puy-en-Velay, (a) 1910, (b) 1911.

While different forms of apparatus and various methods were employed by the several investigators, the results have been rendered comparable by means of reducing all to the same terms. These include (1) the area of the collecting area in square centimeters, (2) the capacity of the collecting instrument in cubic centimeters, (3) the ratio of the capacity of the gauge to the area of the collecting surface, (4) the smallest measurable quantity of electrification, (5) the vertical current through the atmosphere in amperes per square centimeter, (6) the time interval during which the measurements were made, and (8) the maximum value of the current measured.

The author points out the difficulties to be encountered and the dangers to be avoided in investigations of this nature. Because of the great variety of conditions under which the observations were made, especially of climate and of latitude, but few general conclusions can be drawn. However, the more obvious conclusions are as follows:

(1) In general, observations extending over a considerable period of time show a distinct predominance of cases of a positive charge in descending rain or snow, that is, negative charges were in the minority. At Simla the precipitations (rain) measured were found to be positively charged in 75 per cent of the first series and in 78 per cent of the second series of cases; at Puy-en-Velay the proportion was 58 per cent, and at Graz 72 per cent of the cases. Moreover, positively charged rain continued to fall longer than that carrying the opposite charge. At Simla positively charged rain fell during (a) 70 per cent and (b) 73 per cent of the time the measurements were in progress; at Puy-en-Velay the proportion was (a) 60 per cent and (b) 74 per cent, and at Graz 75 per cent of the time.

(2) At Simla and Puy-en-Velay it was found that when the charge carried by the precipitation was very feeble the potential was more frequently negative, and when the charge was relatively strong the potential was more often positive. Moreover, negatively charged precipitation was usually weak in its electrification, while that of the opposite charge was more often strong. At Graz the results were slightly different. Here very weak and very strong charges were usually negative, while only moderate charges were more frequently positive. At all the 8 stations noted the charges carried by precipitation were weak in a large majority of the cases.

[1] Repr. München, Sitz Ber. Ak. Wiss., 1912 (402-429 with 1 pl.). Bericht Nr. 1.

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(3) That extremely large values occasionally occur is shown by the following: Baldit found 13 cases (8 positive and 5 negative) of $500—1100.10^{-15}$ $\frac{amp}{cm^2}$; Simpson, in 1908, found 33 cases (15 positive and 18 negative) of $300—1000.10^{-15}$ $\frac{amp}{cm^2}$, and in 1909, 24 cases (exclusively positive) of $300—613.10^{-15}$ $\frac{amp}{cm^2}$.

(4) When the rate at which the rain fell was slow, that is, the rainfall was light, the precipitation was electrified only about half of the time. When the rainfall was heavy, that is, the rate was high, the precipitation was almost always charged, and the positive precipitation was more frequent than the negative, as well as longer in duration.

(5) The data do not show conclusively whether rain is more frequently positive or more frequently negative in its charge than snow. More data are needed to determine the question.

(6) No conclusions can as yet be given concerning the rate of change of potential and the strength of the charge carried by the precipitation.

In summarizing, the author points out the complexity of the problem and the need of more data. In future investigations it will be very desirable to use some simple yet exact method which will show clearly the influence of one element upon another. A model of the apparatus to be used should first be tested under variable conditions in a laboratory. Because of the great variety of conditions under which precipitation occurs, it will be necessary to carry on investigations in a number of different places and over a long period of time. Simultaneous determinations should be carried on at a number of stations, and the vertical as well as the horizontal changes in the electrification of precipitation should be considered. Because of the difficult nature of the subject the investigator is bound to encounter a great variety of problems from time to time.

A. H. PALMER.

*Department of Terrestrial Magnetism.*

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MARTEN, W., AND KÄHLER, K.: *Aktinometrische und luftelektrische Messungen im Riesengebirge.*[1]

During August, 1912, the authors spent three weeks studying the actinometric and the electrical conditions of the atmosphere. On Riesengebirge (Lat. 51° N., Long. 16° E.), one of the peaks in a mountain chain in east central Germany, two stations, Zillerthal and Schneekoppe, differing greatly in height above the sea, were selected. Meteorological observations were also made at 7 A. M., 2 P. M., and 9 P. M. at each station. Unfavorable weather was experienced throughout the period. Owing to the unchanged barometric state during the three weeks, the observations were made almost entirely under cyclonic conditions. At Zillerthal, 393 meters above sea-level, the means for the period were: temperature, 13.3° C.; relative humidity, 78.4 per cent; cloudiness, 7.7 in a scale of 0—10; wind velocity, 0.9 in a scale of 0—12; and wind direction variable. Similar averages for Schneekoppe, 1615 meters above sea-level, were: temperature, 4.7°C.; relative humidity, 94.4 per cent; cloudiness, 8.8; wind velocity, 5.3; and wind direction prevailing west.

[1] Art. in appendix of Bericht über die Tätigkeit des Preussischen Meteorologischen Institute im Jahre 1912. Berlin, Veröff. met. Inst., No. 256, 1913 [(119)-(132)].

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By means of an Aitken apparatus the number of dust particles was also determined. The average number of particles per cubic centimeter at the base station was found to be 4266 from 31 observations, while at the summit station the corresponding average was 2756 from 16 observations.

Pyrheliometers of various designs were used in the solar radiation measurements. Owing to unfavorable weather conditions, simultaneous observations at the two stations were possible on but one day, August 20. By interpolating from these data the radiation intensities for the two stations for similar heights of the sun were found to be as follows:

| Sun's altitude. | Summit station. | Base station. | Ratio. |
|---|---|---|---|
| 30° | 0.882 gr. cal. | 0.691 gr. cal. | 1.28 |
| 35° | 0.942 " " | 0.767 " " | 1.23 |
| 40° | 1.003 " " | 0.840 " " | 1.19 |
| 45° | 1.062 " " | 0.910 " " | 1.17 |

For a difference of 1211 meters in height above sea-level the radiation intensity at the summit station with the sun at 30° altitude was 28 per cent higher, while with the sun at 45° altitude it was but 17 per cent higher than at the base station. T. Okada and Y. Yoshida found that for a difference of 3700 meters in height on Mount Fuji, Japan, with the sun's altitude of 30° it was 41 per cent, for 40° 29 per cent, and for 50° but 24 per cent greater at the higher station.

The absorption of the rays by the strata of the atmosphere between Schneekoppe and Zillerthal was found to be as follows:

| Sun's altitude. | Absorption. |
|---|---|
| 30° | 0.191 |
| 35° | 0.175 |
| 40° | 0.163 |
| 45° | 0.152 |

Observations of atmospheric electricity were made whenever possible between 6 A. M. and 8 P. M., throughout the three weeks. Among the instruments used were a Benndorf potential registering apparatus, a Lutz-Edelmannsches electrometer, and an Exner electroscope.

It was found that during the middle of the day the electrical (negative) conductivity of the atmosphere was higher at the base station than at the summit station, while the opposite was true during the early morning and the late afternoon. The mean ratio of the conductivity (for all observations) at the base station to that of the summit was in the proportion of 132 to 104. The 12-hour curve of the electrical conductivity of the atmosphere at Zillerthal was the crest of a wave with the maximum occurring about 1.30 P. M., while the curve for the other station was a trough of a wave with a minimum occurring at the same hour. At both stations the diurnal range was marked. At Potsdam the curve for the same period was very nearly a straight line, and the values represented were everywhere lower than at either of the two stations on Riesengebirge.

The fall in potential (negative) in volts per meter and the value of the vertical current (negative) in amperes per square centimeter were also measured. For the summit station the curves of these two elements were again troughs of waves with the minima occurring at 1:30 P. M., while both curves for the base station were crests of waves with maxima at the same hour. The ranges of both elements were again marked at both stations. The corresponding curves for Potsdam resembled those of the base station, but the values were lower throughout and the ranges were less marked. A. H. PALMER.

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## ANGOT'S MAGNETIC CHARTS OF FRANCE FOR JAN. 1, 1901.[1]

The author first calls attention to the magnetic charts published by M. Monreaux in 1898, which showed the distribution of the magnetic elements for Jan. 1, 1896. These charts having become no longer convenient for use, M.

[1] ANGOT, A. Cartes magnètiques de la France au ler janvier 1901. Repr. Ann. bur. cent. mètèor., Paris, 1908, v. 1 (43-110 with 8 pl.)

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Angot was requested by the Bureau of Longitudes to obtain a new series of observations and to bring the charts up to date.

Angot's method of reduction to the selected epoch is briefly as follows. The values of the elements obtained at any station were compared with the magnetograms of Parc Saint-Maur and thus reduced to Jan. 1 of the following year. The values adopted for Jan. 1 of each year at Parc Saint-Maur were the means of the annual values for the year preceding and the year following. The absolute values at any station for Jan. 1 of a year were finally reduced to the common epoch Jan. 1, 1901, by applying the probable secular variation as obtained from charts especially prepared by Angot, and based upon the annual means of the elements ($D$, $I$, and $H$), secured from twenty-two observatories in western Europe for the period from 1883 to 1901. From the values of $D$, $I$, and $H$ thus found, those of the north component, east component, vertical component and total intensity were derived.

For the investigation of anomalies in distribution, the author establishes the limits of accuracy of his results, and states that an anomaly may be suspected when the values obtained at a station differ from those corresponding to a regular distribution by amounts greater than the following limits:

| | | | | | |
|---|---|---|---|---|---|
| | ′ | | γ | | γ |
| For D, | 5 | For H, | 50 | For Y, | 40 |
| " I, | 5 | " X, | 60 | " Z, | 250 |
| | | | | " T, | 250 |

In order to obtain a normal distribution of the elements, the author derives formulæ to represent $D$, $I$ and $H$ as functions of the geographical co-ordinates, latitude and longitude. To this end he divides the entire number of stations under consideration (545) into 26 groups, each group containing about 20 stations, and bounded approximately by 1° to 1.°5 in latitude and longitude. All stations at which anomalies were known to exist are omitted. Assuming that, within the limits of a group, the magnetic elements are linear functions of the geographical co-ordinates, then the arithmetical means of the magnetic elements of all the stations of a group may be regarded as corresponding to the arithmetical means of the geographical co-ordinates. The 26 groups then give 26 centers with corresponding values of the magnetic elements.

The normal values of $D$, $I$ and $H$ are developed in the form of a Taylor's series, stopping at the terms of the second degree, so that, for example:

$$D = a + b\,\phi + c\,\lambda + d\,\phi^2 + e\,\phi\lambda + f\,\lambda^2,$$

where $\phi$ is the latitude, $\lambda$ the longitude, and $a$, $b$, $c$, etc., are constant coefficients to be determined. By substituting the values of $D$, $I$ and $H$, and of $\phi$ and $\lambda$, for the group centers, there are obtained 26 equations for each element. From these equations the values of $a$, $b$, $c$, etc., are obtained by the method of least squares. Thus there result general expressions for $D$, $I$ and $H$, by means of which the values of the elements are computed, first for each of the 26 groups, then for each station in particular. The difference between a value thus calculated and the value derived from observations is the departure from the normal.

A table is given, including all the stations, and showing for each station the date of occupation, the latitude and longitude, the values of $D$, $I$, $H$, $X-Y$, $Z$ and $T$, reduced to the epoch 1901.0, and also the departure from the normal for each of these seven elements. From this table charts were constructed showing the distribution throughout France of the seven quantities named. Reproductions of these charts are appended. There are also two additional charts, one showing, by means of vectors, the directions and amounts of the disturbing forces of Brittany, and the other presenting the anomaly in the Island of Corsica.

Finally the author gives a list of the "departments" of France, with the results obtained in each "department." He classifies the departments into four groups: Normal, almost normal, disturbed, and very disturbed.

DEPARTMENT OF TERRESTRIAL MAGNETISM, W. F. WALLIS.
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# *Terrestrial Magnetism*
*and*
# *Atmospheric Electricity*

VOLUME XVIII DECEMBER, 1913 NUMBER 4


## MAGNETIC DECLINATIONS AND CHART CORRECTIONS OBTAINED BY THE *CARNEGIE* FROM ST. HELENA TO FALMOUTH, ENGLAND, JULY TO SEPTEMBER, 1913.[1]


By L. A. Bauer and W. J. Peters.


(*Minus sign indicates west declination, and plus, east declination.*)

| Date | Position | | Carnegie | Chart Values | | | Chart Corrections | | |
|---|---|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | Brit. | Ger. | U. S. | Brit. | Ger. | U. S. |
| 1913 | ° ′ | ° ′ | ° | ° | ° | ° | ° | ° | ° |
| July 21 | 15 27 S | 6 18W | —24.6 | —24.6 | —24.3 | —23.5 | 0.0 | —0.3 | —1.1 |
| 22 | 13 47 S | 7 40W | —23.8 | —23.8 | —23.9 | —23.3 | 0.0 | +0.1 | —0.5 |
| 23 | 11 26 S | 9 40W | —23.2 | —23.0 | —23.5 | —22.8 | —0.2 | +0.3 | —0.4 |
| 24 | 10 03 S | 10 57W | —22.8 | —22.7 | —23.4 | —22.4 | —0.1 | +0.6 | —0.4 |
| 25 | 8 08 S | 14 13W | —22.4 | —22.1 | —23.0 | —22.1 | —0.3 | +0.6 | —0.3 |
| 26 | 5 20 S | 16.04W | —22.0 | —21.4 | —22.3 | —21.4 | —0.6 | +0.3 | —0.6 |
| 26 | 4 12 S | 17 03W | —21.9 | —21.2 | —22.1 | —21.2 | —0.7 | +0.2 | —0.7 |
| 27 | 3 11 S | 18 05W | —21.6 | —20.9 | —21.8 | —21.0 | —0.7 | +0.2 | —0.6 |
| 28 | 0 59 S | 19.04W | —21.1 | —20.4 | —21.3 | —20.7 | —0.7 | +0.2 | —0.4 |
| 28 | 0 06 S | 19 15W | —21.1 | —20.2 | —21.2 | —20.6 | —0.9 | +0.1 | —0.5 |
| 29 | 0 54 N | 19 22W | —20.8 | —20.0 | —21.0 | —20.4 | —0.8 | +0.2 | —0.4 |
| 29 | 1 42 N | 19 40W | —20.7 | —20.0 | —20.8 | —20.3 | —0.7 | +0.1 | —0.4 |
| 30 | 2 32 N | 20 12W | —20.7 | —20.0 | —20.7 | —20.2 | —0.7 | 0.0 | —0.5 |
| 30 | 3 36 N | 20 40W | —20.7 | —19.9 | —20.6 | —20.1 | —0.8 | —0.1 | —0.6 |
| 31 | 4 38 N | 21 01W | —20.4 | —19.8 | —20.3 | —20.0 | —0.6 | —0.1 | —0.4 |
| 31 | 5 39 N | 21 26W | —20.3 | —19.7 | —20.2 | —19.9 | —0.6 | —0.1 | —0.4 |
| Aug. 3 | 10 19 N | 22 45W | —19.7 | —19.3 | —19.6 | —19.3 | —0.4 | —0.1 | —0.4 |
| 4 | 10 37 N | 22 14W | —19.7 | —19.3 | —19.6 | —19.2 | —0.4 | —0.1 | —0.5 |
| 4 | 10 39 N | 22 16W | —20.0 | —19.3 | —19.6 | —19.2 | —0.7 | —0.4 | —0.8 |
| 7 | 12 42 N | 27 07W | —19.5 | —19.1 | —18.8 | —19.2 | —0.4 | —0.7 | —0.3 |
| 8 | 13 23 N | 27 41W | —19.2 | —19.0 | —18.6 | —19.2 | —0.2 | —0.6 | 0.0 |
| 8 | 14 15 N | 28 41W | —19.3 | —18.8 | —18.3 | —19.1 | —0.5 | —1.0 | —0.2 |
| 9 | 15 11 N | 29 56W | —18.9 | —18.6 | —18.0 | —18.9 | —0.3 | —0.9 | 0.0 |
| 9 | 16 22 N | 31 06W | —18.9 | —18.5 | —17.5 | —18.7 | —0.4 | —1.4 | —0.2 |
| 10 | 19 16 N | 33 12W | —19.1 | —18.5 | —17.0 | —18.4 | —0.6 | —2.1 | —0.7 |
| 11 | 20 26 N | 34 18W | —18.6 | —18.5 | —16.9 | —18.3 | —0.1 | —1.7 | —0.3 |
| 11 | 21 27 N | 35 14W | —18.8 | —18.5 | —16.8 | —18.1 | —0.3 | —2.0 | —0.7 |
| 12 | 22 42 N | 36 06W | —18.9 | —18.6 | —16.9 | —18.1 | —0.3 | —2.0 | —0.8 |

[1] For previous tables, see *Terr. Mag.*, v. 15. pp. 57-82 129-144; v. 16. pp. 133-136; v. 17. 31-32, 97-101, 141-144, 179-180; v. 18. pp. 63-64, 111-112.




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Magnetic Declinations, St. Helena to Falmouth. *Concluded.*

| Date | Position | | Carnegie | Chart Values | | | Chart Corrections | | |
|---|---|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | Brit. | Ger. | U. S. | Brit. | Ger. | U. S. |
| 1913 | ° ′ | ° ′ | ° | ° | ° | ° | ° | ° | ° |
| Aug. 12 | 24 04 N | 37 09W | —19.1 | —18.8 | —17.0 | —18.0 | —0.3 | —2.1 | —1.1 |
| 13 | 25 33 N | 37 54W | —18.9 | —19.2 | —17.1 | —18.2 | +0.3 | —1.8 | —0.7 |
| 13 | 26 50 N | 38 42W | —19.4 | —19.4 | —17.4 | —18.3 | 0.0 | —2.0 | —1.1 |
| 14 | 28 15 N | 39 24W | —19.6 | —19.9 | —18.0 | —18.5 | +0.3 | —1.6 | —1.1 |
| 14 | 29 48 N | 39 54W | —20.2 | —20.3 | —18.7 | —18.9 | +0.1 | —1.5 | —1.3 |
| 15 | 31 07 N | 39 58W | —20.8 | —20.8 | —19.4 | —19.3 | 0.0 | —1.4 | —1.5 |
| 16 | 32 52 N | 40 02W | —21.0 | —21.7 | —20.3 | —20.0 | +0.7 | —0.7 | —1.0 |
| 16 | 33 23 N | 40 03W | —21.8 | —22.0 | —20.6 | —20.2 | +0.2 | —1.2 | —1.6 |
| 18 | 33 23 N | 40 10W | —21.9 | —22.0 | —20.6 | —20.2 | +0.1 | —1.3 | —1.7 |
| 19 | 34 12 N | 38 20W | —22.0 | —22.7 | —21.3 | —20.9 | +0.7 | —0.7 | —1.1 |
| 20 | 34 37 N | 37 32W | —22.1 | —23.0 | —21.6 | —21.2 | +0.9 | —0.5 | —0.9 |
| 20 | 34 49 N | 38 32W | —22.2 | —23.0 | —21.7 | —21.0 | +0.8 | —0.5 | —1.2 |
| 21 | 36 17 N | 39 33W | —23.0 | —23.6 | —22.3 | —21.4 | +0.6 | —0.7 | —1.6 |
| 22 | 37 56 N | 39 48W | —23.9 | —24.4 | —23.2 | —22.2 | +0.5 | —0.7 | —1.7 |
| 23 | 38 48 N | 39 50W | —24.1 | —25.0 | —23.7 | —22.7 | +0.9 | —0.4 | —1.4 |
| 23 | 39 44 N | 39 50W | —25.0 | —25.4 | —24.1 | —23.3 | +0.4 | —0.9 | —1.7 |
| 24 | 40 46 N | 39 46W | —25.6 | —26.0 | —25.0 | —24.3 | +0.4 | —0.6 | —1.3 |
| 25 | 41 28 N | 39 08W | —26.1 | —26.4 | —25.4 | —24.7 | +0.3 | —0.7 | —1.4 |
| 26 | 42 10 N | 38 08W | —25.8 | —26.8 | —26.0 | —25.2 | +1.0 | +0.2 | —0.6 |
| 26 | 42 59 N | 36 20W | —26.0 | —27.1 | —26.5 | —25.2 | +1.1 | +0.5 | —0.8 |
| 27 | 43 30 N | 34 58W | —26.6 | —27.0 | —26.6 | —25.0 | +0.4 | 0.0 | —1.6 |
| 27 | 43 53 N | 33 55W | —26.1 | —26.9 | —26.7 | —25.2 | +0.8 | +0.6 | —0.9 |
| 30 | 44 08 N | 27 07W | —24.0 | —24.3 | —25.0 | —24.3 | +0.3 | +1.0 | +0.3 |
| 31 | 45 58 N | 24 02W | —24.1 | —23.8 | —24.7 | —24.4 | —0.3 | +0.6 | +0.3 |
| Sept. 1 | 46 17 N | 22 26W | —23.4 | —23.3 | —24.2 | —23.8 | —0.1 | +0.8 | +0.4 |
| 2 | 47 19 N | 21 55W | —23.3 | —23.5 | —24.3 | —24.1 | +0.2 | +1.0 | +0.8 |
| 3 | 48 16 N | 20 23W | —23.6 | —23.4 | —24.1 | —23.9 | —0.2 | +0.5 | +0.3 |
| 4 | 48 42 N | 18 32W | —22.8 | —22.7 | —23.5 | —23.1 | —0.1 | +0.7 | +0.3 |
| 5 | 49 22 N | 14 43W | —21.4 | —21.4 | —22.0 | —21.6 | 0.0 | +0,6 | +0.2 |
| 6 | 49 13 N | 13 59W | —21.0 | —21.0 | —21.6 | —21.2 | 0.0 | +0.6 | +0.2 |
| 6 | 49 00 N | 12 55W | —20.6 | —20.6 | —21.0 | —20.6 | 0.0 | +0.4 | 0.0 |
| 8 | 48 23 N | 10 36W | —19.0 | —19.2 | —19.9 | —19.3 | +0.2 | +0.9 | +0.3 |
| 8 | 48 47 N | 11 10W | —19.7 | —19.7 | —20.1 | —19.7 | 0.0 | +0.4 | 0.0 |
| 10 | 49 36 N | 7 32W | —18.2 | —18.2 | —18.7 | —18.2 | 0.0 | +0.5 | 0.0 |

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# THE ATMOSPHERIC POTENTIAL GRADIENT, AND A THEORY AS TO THE CAUSE OF ITS CONNECTION WITH OTHER PHENOMENA IN ATMOSPHERIC ELECTRICITY, TOGETHER WITH CERTAIN CONCLUSIONS AS TO THE EXPRESSION FOR THE ELECTRIC FORCE BETWEEN TWO PARALLEL CHARGED PLATES.

By W. F. G. Swann, A.R.C.S., D. Sc.

The primary purpose of the following paper is to show that the theory of conduction of electricity in gases, combined with the assumption of an atmospheric potential gradient of such a sign that the potential increases with the height, leads us to expect:[1]

(1) That the ratio of the number of positive ions per c. c. at the Earth's surface, to the number of negative ions shall be greater than unity.

(2) That the above ratio shall increase with the potential gradient.

(3) That neither $n_1$, the number of positive ions per c. c., nor $n_2$, the number of negative ions per c. c. at the Earth's surface are the same thing as the numbers which, if the atmospheric field were absent, would exist in order to result in a balance between recombination and formation.

(4) That the atmospheric potential gradient, in a homogeneous atmosphere shall decrease with the height in the neighborhood of the Earth's surface.

(5) That there should be an apparent, but not necessarily true, increase of the rate of ionization with the height.

Various other minor speculations and conclusions are also involved.

(1) and (2) are found to hold experimentally. The agreement or disagreement of (3) with experimental facts does not appear to have been generally discussed. Some writers on atmospheric electricity seem to have assumed that the existence of a constant current density of necessity carries with it the conclusion that the numbers of positive and negative ions which have to exist in order to maintain equilibrium between formation and recombination is

[1] Since the present paper was written, and when it was on the point of being sent to the press, my attention became directed to a paper by Prof. E. R. v. Schweidler (Wien. Ber. 117, 1908), in which much of the ground work of the part of the present paper concerned with the application to atmospheric electricity has been covered. While fully recognizing Schweidler's priority in those parts of the work which he has covered, relating to the decrease of the potential gradient with the height and the increase of the ratio of the number of positive to the number of negative ions, I have thought it advisable not to omit the work bearing on these questions, partly for the sake of completeness in the demonstration and partly because Schweidler's paper seems, unfortunately, to have been overlooked by writers in atmospheric electricity.—W. F. G. S.



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the same as if the field were absent, a conclusion, the fallacy of which becomes evident when the differential equations governing the motions of the ions are examined. (4) has been shown to hold experimentally for our atmosphere. With regard to (5), it may be remarked that the general opinion is that the rate of ionization does increase with the height.

Before entering upon more elaborate calculations, it will perhaps be well to illustrate the importance of a careful scrutiny of the exact mechanism of the production of the conduction current by taking a numerical example, which will illustrate the errors which may be made by a neglect of the actual condition of tendency towards saturation produced by the atmospheric electric field in our atmosphere. Measurements of the number of ions indicate that about 1000 of each kind are to be found per c. c. Let us consider the negative ions. The number $\delta n$ crossing one sq. cm. per second is $\delta n = n_2 v_2 X$, where $n_2$ is the number of negative ions per c. c., $v_2$ the velocity, and $X$ the field. Now $v_2$ = about 1.6 cm./sec. per volt per cm. For the Earth's field $X$ = say, one volt/cm., so that if $n_2 = 1000$

$$\delta n = 1600 \qquad (1)$$

Now if the sq. cm. through which these ions pass is situated $h$ cms. above the ground, it is obvious that if there are less than 1600 negative ions produced in a cylinder of base one sq. cm. and height $h$, our above calculation is one which can not correspond to the facts.

If $q$ is the rate of formation and $\alpha$ the constant of recombination, and if we assume, as appears to be often done in atmospheric electricity, that the measured numbers $n_1$ and $n_2$ of positive and negative ions are such as would correspond to a state of equilibrium between formation and recombination in the absence of the field, we shall have $q = \alpha n_1 n_2$. Putting in observed values of $n_1$ and $n_2$, we find approximately $n_1 n_2 = 10^6$. Now $\alpha = 1.1 \times 10^{-6}$, hence $q = 1.1$.

It is consequently obvious that it would take a column of air about 15 meters high to produce enough ions to supply the necessary number required by (1), even supposing that these ions could be transferred across in time, and if our sq. cm. were only one meter above the ground, nothing like the number given by (1) could cross it per second. Of course, what actually happens is that an adjustment of the field and of the number of ions at differ-

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ent heights has to be made which does give consistence in the calculations, and it is the purpose of this paper to see what conclusions arise when we attempt to make the necessary adjustment.

The above numerical example is sufficient to show that the questions involved are really serious ones, and do not merely affect some microscopically thin layer in the immediate vicinity of the ground, but rather the very regions in which our experiments are performed.

## The Field Between Two Parallel Charged Plates and Its Application to a Homogeneous Atmosphere.

The actual atmosphere is too complicated to deal with, and, where no better method is open, we shall attempt to draw our conclusions at any rate qualitatively by considering a homogeneous atmosphere of height $2H$. The origin shall be midway between the plates, and $x$ shall be measured downwards.

We shall imagine that there is a conducting plate at the top of the atmosphere, the Earth constituting the lower plate, so that the problem is one of the current between parallel plates. Perhaps the highly ionized air which we imagine to exist in the higher regions of the atmosphere may serve as a physical analogue of our upper conducting plate. As a matter of fact, it will turn out that, in view of the great extent of the atmosphere, the conditions in the neighborhood of the surface, and possibly for a considerable distance up are practically independent of the state of the atmosphere at great heights.

The method of deducing the variation of the force between the plates will be on the lines of that adopted by Sir J. J. Thomson (Conduction of Electricity through Gases, 2nd Ed., p. 84 *et seq*). An interesting point arises in this connection. I find, for reasons to be presently stated, that the investigation in "Conduction through Gases" involves an assumption which virtually restricts the solution to the case where the distance between the plates is infinite. The effects on the conclusions there drawn are, however, except for very small distances between the plates, inappreciable for the values of the rate of formation of ions generally dealt with in experiments on the force between plates. If, however, we had to deal with rates of formation as small as the natural rates of formation, the results would be quite inapplicable to plates separated by 5 cm., for instance. Though in the atmosphere our problem is virtually equivalent to one where the plates are infi-

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nitely distant, the other problem where the distance is of ordinary laboratory dimensions is of considerable theoretical interest from a purely physical point of view, and the modification of the solution applicable to that case will be dealt with also.

The following notation will be used: $n_1$ and $n_2$ represent the actual numbers of positive and negative ions per c. c., $q$ the rate of formation of ions, $\alpha$ the rate of recombination of the ions, $e$ the electronic charge, $X$ the field, $i$ the current density, $v$ the specific velocity of the ions.

We shall generally have to take $v$ to be the same for the positive and the negative ions, as otherwise our equations will become too difficult to solve. Since the specific velocities of the positive and negative ions are in the ratio 1.4 to 1.7, the assumption of their equality will probably not affect our conclusions very seriously. Following J. J. Thomson, we get, by Poisson's equation:

$$\frac{dX}{dx} = 4\pi (n_1 - n_2) e \tag{2}$$

$$\text{also} \qquad i = (n_1 + n_2) e v X \tag{3}$$

so that, from (2) and (3)

$$2n_1 ev = \left\{ \frac{i}{X} + \frac{v}{4\pi} \frac{dX}{dx} \right\} \tag{4}$$

$$2n_2 ev = \left\{ \frac{i}{X} - \frac{v}{4\pi} \frac{dX}{dx} \right\} \tag{5}$$

We, of course, assume that the steady state has been attained, so that $i$ is constant at all parts.

The equations giving the excess of formation of ions over recombination are

$$v \frac{d}{dx} (n_1 X) = q - \alpha n_1 n_2 \tag{6}$$

$$-v \frac{d}{dx} (n_2 X) = q - \alpha n_1 n_2 \tag{7}$$

It is our purpose to get a differential equation for $X$.

Again following J. J. Thomson, we obtain from (2), (6), and (7)

$$\frac{d^2 X^2}{dx^2} = \frac{16\pi e}{v} \left( q - \alpha n_1 n_2 \right) \tag{8}$$

So that substituting in (8) the values of $n_1$ and $n_2$ given by (4) and (5), we get

$$\frac{d^2 X^2}{dx^2} = \frac{16\pi e}{v} \left[ q - \frac{\alpha}{4 e^2 v^2 X^2} \left\{ i^2 - \left( \frac{v}{8\pi} \frac{dX^2}{dx} \right)^2 \right\} \right]$$

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Thus on putting $X^2=y$ and $\frac{dy}{dx}=p$ we obtain on integration, as is shown in "Conduction through Gases"

$$\frac{v^2p^2}{64\pi^2}-i^2=\frac{qev}{2\pi\left(1-\frac{a}{8\pi ev}\right)}y+Cy^{\frac{a}{8\pi ev}} \tag{9}$$

$$\text{Put } \frac{a}{8\pi ev}=\beta \text{ so that}$$

$$\frac{v^2p^2}{64\pi^2}-i^2=Cy^{\beta}+\frac{qev}{2\pi(1-\beta)}y \tag{10}$$

Differentiating with respect to $x$.

$$\frac{v^2}{32\pi^2}\frac{dp}{dx}=\beta Cy^{\beta-1}+\frac{qev}{2\pi(1-\beta)} \tag{11}$$

$$\text{Now } \frac{dp}{dx}=\frac{d}{dx}\left(\frac{dX^2}{dx}\right)=2\frac{d}{dx}\left(X\frac{dX}{dx}\right)=2X\frac{d^2X}{dx^2}+2\left(\frac{dX}{dx}\right)^2 \tag{12}$$

At $x=0$, $\frac{dX}{dx}=0$, since at that point $n_1=n_2$ from symmetry. In "Conduction through Gases," second edition, page 87, Sir J. J. Thomson considers that $\frac{d^2X}{dx^2}$ is also zero at $x=0$, or, at any rate, he confines the calculation to a case such that it is zero.

Now it will turn out that the value of $\left(\frac{d^2X}{dx^2}\right)_{x=0}$ is never absolutely zero, but is a quantity depending on the distance between the plates. The assumption that $\frac{d^2X}{dx^2}$ is zero at $x=0$ will be found to be equivalent to restricting the problem to the case where the plates are an infinite distance apart. This difficulty has not made itself evident in the calculation in "Conduction through Gases," because it has not been necessary for the purpose there in hand to make use of the distance between the plates, so that that quantity has not explicitly appeared.

It may be mentioned that the assumption $\frac{d^2X}{dx^2}=0$ at $x=0$ and the consequent virtual restriction to the case of plates an infinite distance apart, is responsible for the rather curious result deduced on page 87 *l. c.*, in which it appears that the ratio of the force near the plate to the force midway between them is independent of the rate of production of ions and of the current between the plates. It must be remarked, however, as will presently appear, that the calculation in "Conduction through Gases" applies

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with accuracy to the experiments which are there under discussion in connection with that calculation, experiments in which $q$ is much larger than in the present case. At least this is so, provided the plates are not too near together.

Thus, in the present calculation we shall not assume $\left(\frac{d^2X}{dx^2}\right)_{x=0}=0$ but shall write $\left(\frac{d^2X}{dx^2}\right)_{x=0}=\eta$

From (11) and (12), putting $y=X_0^2$ at $x=0$, and remembering that $\left(\frac{dX}{dx}\right)_{x=0}=0$ we obtain

$$C=\frac{qev}{2\pi\beta(\beta-1)X_0^{2\beta-2}}\left\{1-\frac{(1-\beta)X_0\eta v}{8\pi qe}\right\}$$

Put $$\frac{X_0\eta v}{8\pi qe}=\epsilon$$

where, however, it must not be thought that $\epsilon$ is necessarily a small quantity.

Then $$C=\frac{qev\{1-(1-\beta)\epsilon\}}{2\pi\beta(\beta-1)X_0^{2\beta-2}}$$

Hence (10) becomes

$$\frac{v^2p^2}{64\pi^2}-i^2=\frac{qev}{2\pi(\beta-1)}\left\{\frac{[1-(1-\beta)\epsilon]}{\beta X_0^{2\beta-2}}X^{2\beta}-X^2\right\} \quad (13)$$

Again, since $p=0$ at the origin, we find from (13)

$$i^2=\frac{qev}{2\pi\beta}X_0^2(1-\epsilon) \quad (14)$$

If we put in the value of $\beta$ given after equation (9) we find[2]

$$i=2\sqrt{\frac{q}{a}}evX_0(1-\epsilon)^{\frac{1}{2}} \quad (15)$$

Thus, substituting in (13) from (14), we obtain

$$\frac{v^2p^2}{64\pi^2}=\frac{qev}{2\pi\beta}X_0^2\left\{1+\frac{\beta}{1-\beta}\left(\frac{X}{X_0}\right)^2-\frac{1}{1-\beta}\left(\frac{X}{X_0}\right)^{2\beta}+\epsilon\left[\left(\frac{X}{X_0}\right)^{2\beta}-1\right]\right\} \quad (16)$$

Substituting for $\beta$ in the external factor and remembering that $p=\frac{dX^2}{dx}$ we have

[2] An interesting point may be noted at this stage. It will be noted that $\sqrt{\frac{q}{a}}$ is the number $N$ of ions to be found per c. c. such as to cause equilibrium between rate of formation and rate of recombination, when the electric field is absent. Thus, when $\epsilon$ is zero, *i. e.*, when $\frac{d^2X}{dx^2}$ is zero at $x=0$ we find that midway between the plates $i=2NevX_0$ *i. e.*, for this case the gas behaves at that point as though the field produced no influence on the number of ions. The gas would, in fact, obey Ohm's law at this point, and have the ordinary conductivity for infinitely small fields. If $\epsilon$ is not zero, however, this no longer holds, and $i$ is not a linear function of $X_0$ at this point.

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$$\frac{dX}{dx} = 8\pi e\sqrt{\frac{q}{a}}\frac{X_0}{X}\left\{1 + \left(\frac{\beta}{1-\beta}\right)\left(\frac{X}{X_0}\right)^2 - \left(\frac{1}{1-\beta}\right)\left(\frac{X}{X_0}\right)^{2\beta} + \epsilon\left[\left(\frac{X}{X_0}\right)^{2\beta} - 1\right]\right\}^{\frac{1}{2}} \quad (17)$$

Writing $\frac{X}{X_0} = \zeta$ we obtain

$$dx = \frac{X_0\zeta\, d\zeta}{8\pi e\sqrt{\frac{q}{a}}}\left\{1 + \left(\frac{\beta}{1-\beta}\right)\zeta^2 - \left(\frac{1}{1-\beta}\right)\zeta^{2\beta} + \epsilon\left[\zeta^{2\beta} - 1\right]\right\}^{-\frac{1}{2}} \quad (18)$$

We can, at this stage, obtain an expression for the ratio of the field at a plate to the field $X_0$ midway between the plates. At the lower plate $n_2 = 0$ so that, from (5)

$$\frac{i}{X} = \frac{v}{4\pi}\frac{dX}{dx}$$

Hence, using (15), we have, at the lower plate

$$\frac{dX}{dx} = \frac{4\pi i}{vX} = 8\pi\sqrt{\frac{q}{a}}e\frac{X_0}{X_1}(1-\epsilon)^{\frac{1}{2}} \quad (19)$$

Equating the corresponding values of $\frac{dX}{dx}$ given by (17) and (19), for the lower plate, we find

$$1 + \frac{\beta}{1-\beta}\left(\frac{X_1}{X_0}\right)^2 - \left(\frac{1}{1-\beta}\right)\left(\frac{X_1}{X_0}\right)^{2\beta} + \epsilon\left[\left(\frac{X_1}{X_0}\right)^{2\beta} - 1\right] = 1 - \epsilon$$

from which we readily derive

$$\frac{X_1}{X_0} = \left\{\frac{\beta}{1 - \epsilon(1-\beta)}\right\}^{\frac{1}{2\beta-2}} \quad (20)$$

When $\epsilon$ is zero, this leads to the result found by Sir J. J. Thomson, viz., $\frac{X_1}{X_0} = \beta^{\frac{1}{2\beta-2}}$. (It must be observed that the quantity here called $\beta$ is the reciprocal of the $\beta$ used in "Conduction through Gases.") In the present case, however, $X_1/X_0$ depends upon $\epsilon$ i. e., on $\frac{X_0\eta v}{8\pi q e}$ which is a function of $X_0$ and also of $\eta$ and the latter quantity depends, as we shall see, upon the distance between the plates.

On integrating (18), an arbitrary constant will appear, which constant will have to be adjusted so that when $\zeta = 1$, $x = 0$. It turns out, however, that if $\epsilon$ (which is proportional to $\frac{d^2X}{dx^2}$ at $x=0$) is zero, the indefinite integral will be infinite, for on putting



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$\zeta = 1 + \mu$ in (18), expanding, and neglecting terms smaller than $\mu^2$ we get:

$$dx = \frac{X_0}{8\pi e\sqrt{\frac{q}{a}}} \left\{ \frac{d\mu}{[2\beta\mu^2 + \beta\epsilon(2\beta - 5)\mu^2 + 2\beta\epsilon\mu]^{1/2}} \right\} \tag{21}$$

If $\epsilon$ is zero, this becomes

$$dx = \frac{X_0}{8\pi e\sqrt{\frac{2\beta q}{a}}} \frac{d\mu}{\mu}$$

Thus, in the neighborhood of $\zeta = 1$, *i.e.* of $\mu = 0$ the indefinite integral approximates to the form $\frac{X_0}{8\pi e\sqrt{\frac{2\beta q}{a}}} \log \mu$ which is $-\infty$ when $\mu = 0$. Thus the arbitrary constant arising from the integration of (18) is infinite, since it must just cancel the infinite indefinite integral corresponding to $\zeta = 1$. This tells us that the points for which $\zeta$, *i.e.* $\frac{X}{X_0}$ has any value finitely different from unity are at an infinite distance from the origin. The lower plate, where $\frac{X_1}{X_0}$ has the value finitely different from unity, obtained for the present case by putting $\epsilon = 0$ in (20), is consequently at an infinite distance from the origin midway between the plates. If $\epsilon$ is not zero, (18) reduces to

$$dx = \frac{X_0 d\mu}{8\pi e\sqrt{\frac{2q\beta\epsilon}{a}}} \left\{ \frac{1}{\mu^{1/2}} + \left(\frac{5}{4} - \frac{1}{2\epsilon} - \frac{\beta}{2}\right)\mu^{1/2} \right\}$$

leading on integration to

$$x = \frac{2X_0}{8\pi e\sqrt{\frac{2q\beta\epsilon}{a}}} \left\{ \mu^{1/2} + \left(\frac{5}{12} - \frac{1}{6\epsilon} - \frac{\beta}{6}\right)\mu^{3/2} \right\} \tag{22}$$

which is no longer infinite when $\mu = 0$ but zero. The constant arising from the integration of (18) is, in this case, finite, and the places, such as the lower plate, where $\zeta$ differs from unity by finite amounts, are at a finite distance from the origin. If we assign a definite value to $\epsilon$ we can, in terms of it, determine the distance between the plates, for, we can, in terms of $\epsilon$, determine from (20) the value of $\zeta$ for the lower plate, *i. e.*, the value $\frac{X_1}{X_0}$. It is only now necessary to integrate (18) between the limits $\zeta = 1$ and $\zeta = \frac{X_1}{X_0}$ to obtain the distance between the plates as a function of $\epsilon$ which is proportional to $X_0\left(\frac{d^2X}{dx^2}\right)_{x=0}$. Conversely, it will be

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obvious that, if $H$ and $X_0$ are assigned, it is theoretically possible to determine $\left(\frac{d^2X}{dx^2}\right)_{x=0}$ in terms of $H$ and $X_0$.

In order to realize the large modification in the expression for the force between the plates resulting from the above considerations, when the plates are not very far apart, and when $q$ is not very large, we shall consider an example or two.

We shall take $\alpha = 1.1 \times 10^{-6}$, $v = 1.6$ cm./sec. per volt per cm., *i. e.*, 480 cm./sec. per *E. S. U.* per cm., $e = 4.7 \times 10^{-10}$ *E. S.U.* so that $\beta = 0.194$. When $\epsilon = 0$ which is the case treated in "Conduction through Gases," we find from (20)

$$\frac{X_1}{X_0} = 2.766$$

We shall assign different values to $\epsilon$ and we must then solve equation (18) graphically by plotting the coefficient of $d\zeta$ against $\zeta$ and measuring areas. The semi-distance between the plates will correspond to the area included between $\zeta = 1$ and the value $\zeta = \frac{X_1}{X_0}$ given by (20).

The expression (22) can be more conveniently used for obtaining the portions of the integral in the immediate neighborhood of $\zeta = 1$.

It is hardly necessary to give the arithmetical details involved. The accompanying Table I will indicate the results obtained; $q$ is taken as 11 ions per second per cc., and $F$ is the field midway between the plates in volts per cm. Thus we see that for a case where $F$ is one volt per cm., $q = 11$ and the plates are 14.3 cms. apart, the field would be *practically uniform* between the plates, since $\frac{X_1}{X_0}$ is practically unity.

TABLE I.

| $\epsilon = \frac{X_0 \eta v}{8\pi q e}$ | $\frac{X_1}{X_0}$ | $\left(\frac{8\pi e}{X_0}\sqrt{\frac{q}{\alpha}}\right)H$ | $H$ (cms) |
|---|---|---|---|
| 0 | 2.766 | $\infty$ | $\infty$ |
| 0.1 | 2.625 | 9.4 | 840F |
| 0.5 | 2.008 | 4.9 | 440F |
| 0.8 | 1.455 | 2.6 | 230F |
| 0.999 | 1.0026 | 0.16 | 14.3F |

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The question may be asked that if this is so, how is it that experiments with plates at a small distance apart have shown variation in the field?[3] The answer is to be sought in the fact that in these experiments $q$ was much greater than the value here assumed for the atmosphere. The above value $q = 11$ gives $\sqrt{\frac{q}{\alpha}} = 3.2 \times 10^3$. Now in an actual laboratory experiment, where the current between the plates is perhaps 0.04 *E. S. U.* per sq. cm. per second, we have $\sqrt{\frac{q}{\alpha}}\, evX = 0.02$ where $X$ is say, 10 volts per cm., *i. e.*, $\frac{1}{300}$ *E. S. U.*, so that $\sqrt{\frac{q}{\alpha}}$ is about $3 \times 10^6$, *i. e.*, about 1000 times the above value. Thus, since the values of $H$ in the above table are proportional to $1/\sqrt{\frac{q}{\alpha}}$ it is obvious that if $\sqrt{\frac{q}{\alpha}}$ is increased 1000 times we shall have to divide the number in the last column by 1000, so that where $\frac{X_1}{X_0} = 2.008$, $H$ will only be $0.440F$, and plates as much even as 10 cm. apart would correspond to a value of $\frac{X_1}{X_0}$ approximating closely to the upper limit 2.766 and to a field distribution of the same nature as for plates an infinite distance apart.

## Variation of the Atmospheric Potential Gradient with the Height.

We shall now proceed to apply the foregoing to the case of the atmosphere, where the distance between the plates is very large. We shall, however, as a matter of physical interest at the same time discuss the bearing of the results on problems where the plates are close together.

We have seen from Table I that the value of $\frac{X_1}{X_0}$ is not altered very much by widening the semi-distance between the plates from $840F$ cms to infinity, $F$ being the potential gradient in volts per cm., which has a value of the order of unity for the atmosphere. Thus, in the case of the atmosphere, we may take $\epsilon = 0$, so that (18) becomes

$$dx = \frac{X_0 \zeta\, d\zeta}{8\pi e \sqrt{\frac{q}{\alpha}}} \left\{ 1 + \frac{\beta}{1-\beta}\zeta^2 - \frac{1}{1-\beta}\zeta^{2\beta} \right\}^{-\frac{1}{2}} \qquad (23)$$

To obtain the distances from the Earth's surface corresponding to the various values of $\zeta$, *i. e.*, of $\frac{X}{X_0}$ we must plot

$$\frac{X_0 \zeta}{8\pi e \sqrt{\frac{q}{\alpha}}} \left\{ 1 + \frac{\beta}{1-\beta}\zeta^2 - \frac{1}{1-\beta}\zeta^{2\beta} \right\}^{-\frac{1}{2}} \text{ against } \zeta$$

[3] See "Conduction of Electricity through Gases," second edition, pages 81–82.

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and measures the areas from $\zeta = 2.766$ to the various values for which the corresponding distances are required. Doing this, and putting $X_0$ as 150 volts per meter, and $q = 11$, we obtain the results in Table II, in which the first column represents $\frac{X}{X_0}$ the second column, headed $h$ represents distances from the ground in meters, estimated in the above manner, and the third column represents the values of $X$ in volts per meter corresponding to the given values of $\frac{X}{X_0}$. The last column in the table will presently be explained.

TABLE II.

| $\frac{X}{X_0}$ | $h$ meters | $X$ | $\frac{n_1}{n_2}$ |
|---|---|---|---|
| 1 | $\infty$ | 150 volts per meter | 1.000 |
| 1.005 | 17.0 meters | 150.7 " " " | 1.006 |
| 1.01 | 15.5 " | 151.5 " " " | 1.012 |
| 1.1 | 10.3 " | 165 " " " | 1.132 |
| 1.3 | 7.45 " | 195 " " " | 1.44 |
| 1.5 | 5.85 " | 225 " " " | 1.85 |
| 1.8 | 4.10 " | 270 " " " | 2.78 |
| 2 | 3.10 " | 300 " " " | 3.79 |
| 2.3 | 1.80 " | 345 " " " | 6.93 |
| 2.5 | 1.00 " | 375 " " " | 13.0 |
| 2.766 | 0.00 " | 415 " " " | $\infty$ |

The accompanying curve, Fig. 1, shows $X$ plotted against the distance $h$ from the ground. It will be noticed that the variation in the potential gradient with height remains quite appreciable up to 17 meters, and in the neighborhood of the ground the variation is very pronounced. The defect of the theory is that the height 17 meters at which the potential gradient ceases to diminish appreciably, while large compared with the dimensions of ordinary apparatus, is not large viewed from a cosmical standpoint, and the difficulty remains of explaining the continued decrease of the potential gradient for higher altitudes found by many observers. It may be remarked that the values of $h$ we have obtained depend upon the value $q = 11$ which we have taken. An examination of 23 shows that $x$ is proportional to $\frac{1}{1-q}$, so that if $q$ were unity instead of 11, all the values of $h$ in the table would have to be multiplied by $\sqrt{11}$, *i. e.*, they would be increased about three times. The variation of $X$ with the height presumably extends, however, to very much greater distances than even 50 meters, and though

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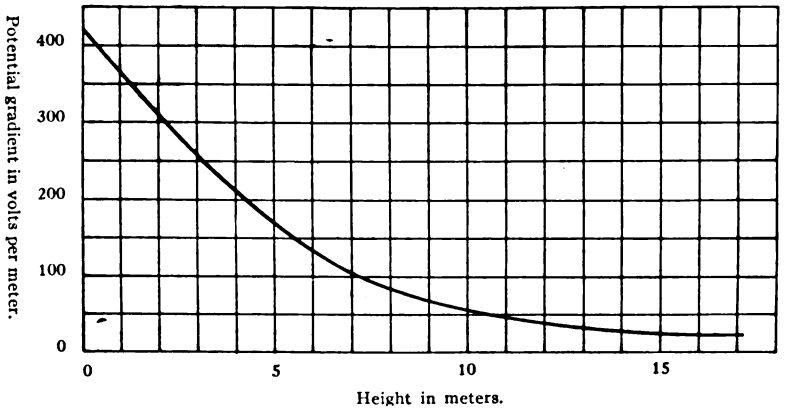
we could increase the values of $h$ in our table without limit by imagining a sufficiently small value of $q$, we are restricted by the condition that $q$ cannot be less than is given by $q = \alpha n_1 n_2$, and since $\alpha$ is $1.1 \times 10^{-6}$ and $n_1$ and $n_2$ are experimentally found to be about 1000, $q$ cannot be much less than 1. The value $q = 11$ taken in the above calculation corresponds to the values which seem to be generally found for the number of ions per cubic centimeter produced in closed vessels. An interesting point in connection with the relationship between $q$ and $n_1 n_2$ will presently be discussed.

The assumption of a smaller value of $\beta$ would lead to larger values of the heights for given values of $\frac{X}{X_0}$ but since $\beta$ only in-

FIG. I




volves $\alpha$, $e$ and $v$, which quantities are fairly definitely limited, it is not possible to draw very much upon this source for the purpose of improving the agreement.

Though, if the atmospheric potential gradient does go on decreasing appreciably with the height to great heights, it is possible that a more complete theory than that given will be necessary to bring out the fact, it is interesting to note that the theory in its present form does indicate a variation over a pretty considerable distance. It is possible, however, that the main portion of the potential gradient variation experimentally measured at *great heights* is dependent for its explanation on the inclusion in our theory of some of the circumstances which we have for simplicity omitted, and that the other variations which our theory in its pres

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ent form predicts is a real phenomenon, possibly not yet experimentally observed, partly because it is masked by the erratic fluctuations known to exist near the ground and partly because experiments on the variation of the force with the height have apparently been mainly confined to points so high as to be out of the region where the effect here involved is appreciable.

Laboratory experiments on the variation of the force between plates have shown that the regions where the force varies appreciably are closely confined to the plates for small differences of potential, but as already pointed out, in these experiments the values of $q$ are enormously larger than in the atmosphere. It is the extremely small value of $q$ in the atmosphere which is responsible for the theory indicating an appreciable variation of $X$ extending even as far from the surface as it does.

Ratio of the number, $n_1$, of positive to the number, $n_2$, of negative ions per cubic centimeter.

From (2) and (17):

$$(n_1 - n_2)e = \frac{1}{4\pi}\frac{dX}{dx} = 2e\sqrt{\frac{q}{a}}\frac{X_0}{X}\left\{1 + \frac{\beta}{1-\beta}\left(\frac{X}{X_0}\right)^2 - \frac{1}{1-\beta}\left(\frac{X}{X_0}\right)^{2\beta} + \epsilon\left[\left(\frac{X}{X_0}\right)^{2\beta} - 1\right]\right\}^{\frac{1}{2}} \quad (24)$$

From (3) and (15):

$$(n_1 + n_2)e = \frac{i}{vX} = 2e\sqrt{\frac{q}{a}}\frac{X_0}{X}\left(1-\epsilon\right)^{\frac{1}{2}} \quad (25)$$

$$\therefore \frac{n_1 - n_2}{n_1 + n_2} = (1-\epsilon)^{-\frac{1}{2}}\left\{1 + \frac{\beta}{1-\beta}\left(\frac{X}{X_0}\right)^2 - \frac{1}{1-\beta}\left(\frac{X}{X_0}\right)^{2\beta} + \epsilon\left[\left(\frac{X}{X_0}\right)^{2\beta} - 1\right]\right\}^{\frac{1}{2}}$$

from which it is possible to determine $\frac{n_1}{n_2}$ for any value of $\frac{X}{X_0}$, and hence for any point between the plates. For the case where $\epsilon = 0$

$$\frac{n_1 - n_2}{n_1 + n_2} = \left\{1 + \frac{\beta}{1-\beta}\left(\frac{X}{X_0}\right)^2 - \frac{1}{1-\beta}\left(\frac{X}{X_0}\right)^{2\beta}\right\}^{\frac{1}{2}}$$

or writing $f\left(\frac{X}{X_0}\right)$ for the righthand side

$$\frac{n_1}{n_2} = \frac{2}{1 - f\left(\frac{X}{X_0}\right)} - 1 \quad (26)$$

The values of $\frac{n_1}{n_2}$ corresponding to the various values of $\frac{X}{X_0}$ and consequently of $h$ in Table II are to be found in the fourth column.

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The theory thus indicates what is experimentally found, an excess of the number of positive over the number of negative ions. The excess indicated in the *immediate* vicinity of the ground is enormous, but it must be remembered that this is bound up with the conditions we have employed at the surface, viz., $n_2 = 0$, which would be considerably modified if there were greater ionization there than is to be found higher up. The ratio $\frac{n_1}{n_2}$ experimentally found is about 1.2 and corresponds to the theoretical value as given by Table II for a height of 10 meters. As in the potential gradient, the theory indicates a more rapid variation in the neighborhood of the ground than is experimentally found, and this variation seems to exist at the expense, so to speak, of a variation in higher regions. It is as though the atmosphere were striving to attain the steady state predicted by the theory, while a continual smoothing out process were taking place due to convection, diffusion, etc. A series of values experimentally found for $\frac{n_1}{n_2}$ is given in Table V.

It may be remarked that if the potential gradient were reversed in sign, $\frac{n_1}{n_2}$ should become less than unity, and it would be of interest to make suitable observations when occasion arose to test this point.

Variation of $\frac{n_1}{n_2}$ with the field.

We see from (26) that $\frac{n_1}{n_2}$ depends only on $\frac{X}{X_0}$ and we see from Table II that it increases with $\frac{X}{X_0}$. Again, from (23), the value of $h$ corresponding to any value $J$ of $\frac{X}{X_0}$ is

$$h = \frac{X_0}{8\pi e\sqrt{\frac{q}{a}}} \int_J^{2.766} \zeta \left\{ 1 + \frac{\beta}{1-\beta}\zeta^2 - \frac{1}{1-\beta}\zeta^{2\beta} \right\}^{-\frac{1}{2}} d\zeta$$

and is thus proportional to $X_0$. Thus the height at which a given value of $\frac{X}{X_0}$ is to be found increases with $X_0$, and consequently, since $\frac{X}{X_0}$ decreases with the height, the value of $\frac{X}{X_0}$ for a given height increases with $X_0$, and consequently $\frac{n_1}{n_2}$ increases with $X_0$, *i. e.*, with the atmospheric potential gradient.

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The following table, No. III, represents, for several values of $X_0$, the values of $h$ for which different values of $\frac{X}{X_0}$ are to be found.

TABLE III.

| | Values of $h$ | | | | |
|---|---|---|---|---|---|
| $\frac{X}{X_0}$ | $X_0=$ 50 volts per meter | $X_0=$ 100 volts per meter | $X_0=$ 150 volts per meter | $X_0=$ 200 volts per meter | $X_0=$ 250 volts per meter |
| | $\infty$ | $\infty$ | $\infty$ | $\infty$ | $\infty$ |
| 1.005 | 5.7 meters | 11.4 meters | 17.0 meters | 22.8 meters | 28.5 meters |
| 1.01 | 5.2 " | 10.4 " | 15.5 " | 20.8 " | 26.0 " |
| 1.1 | 3.43 " | 6.86 " | 10.3 " | 13.72 " | 17.15 " |
| 1.3 | 2.48 " | 4.96 " | 7.45 " | 9.92 " | 12.40 " |
| 1.5 | 1.95 " | 3.90 " | 5.85 " | 7.80 " | 9.75 " |
| 1.8 | 1.37 " | 2.74 " | 4.10 " | 5.48 " | 6.85 " |
| 2 | 1.03 " | 2.06 " | 3.10 " | 4.12 " | 5.15 " |
| 2.3 | 0.60 " | 1.20 " | 1.80 " | 2.40 " | 3.00 " |
| 2.5 | 0.33 " | 0.66 " | 1.00 " | 1.32 " | 1.65 " |
| 2.766 | 0.00 " | 0.00 " | 0.00 " | 0.00 " | 0.00 " |

Now taking for example the height 3.5 meters, we can find by interpolation the values of $\frac{X}{X_0}$ which correspond to this value of $h$ for each value of the field $X_0$. It then becomes possible to calculate from (26) the value of $\frac{n_1}{n_2}$ corresponding to these values of $X_0$. Table IV contains the results.

TABLE IV.

| $X_0$ volts per meter | $\frac{X}{X_0}$ for a height of 3.5 meters | $\frac{n_1 - n_2}{n_1 + n_2}$ | $\frac{n_1}{n_2}$ |
|---|---|---|---|
| 50 | 1.096 | 0.0593 | 1.126 |
| 100 | 1.603 | 0.3584 | 2.12 |
| 150 | 1.920 | 0.462 | 3.33 |
| 200 | 2.109 | 0.357 | 4.60 |
| 250 | 2.230 | 0.290 | 6.90 |

The variation of $\frac{n_1}{n_2}$ near the Earth's surface with the atmospheric potential gradient is larger than is found experimentally, but this fact is closely bound up with the cause which makes the variation of the potential gradient with height larger than is found experimentally.



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## Dissipation.

Since the positive ions are in excess of the negative and $\frac{n_1}{n_2}$ is greater than unity, we should expect that the dissipation coefficient $a_-$ for a negative charge (which depends mainly on the positive ions) would be greater than the dissipation coefficient $a_+$ for a positive charge. This is found to be the case. If the experimental numbers be examined, however, it will be found that $\frac{a_-}{a_+}$ is greater than $\frac{n_1}{n_2}$. It is possible that this is due to the fact that the behavior of the dissipation apparatus is largely controlled by the earthed table on which it happens to be placed, since, as we have seen, in the immediate neighborhood of the Earth, and consequently of an earthed support, there will, in the steady state, be a particularly large deficit of negative ions. The values of $n_1$ and $n_2$ as obtained by the Ebert apparatus will not be affected to the same extent, since the ions are supplied to the apparatus largely by air which has come from places remote from the support.

Table V, taken from Dr. Chree's article on atmospheric electricity in the 11th edition of the Encyclopædia Britannica, represents experimental values of $\frac{a_-}{a_+}$ and $\frac{n_1}{n_2}$ obtained in different localities and for different atmospheric potential gradients. In Dr. Chree's article, the column here headed $\frac{n_1}{n_2}$ is headed $Q_1$, and there refers to the ratio of the total positive charge per c. c. to the total negative charge per c. c. This is, of course, the same thing as $\frac{n_1}{n_2}$ if we assume that the positive and negative ions have equal charges.

Table V.

| Potential gradients in volts per meter | $\frac{a_-}{a_+}$ | | | Karasjok $\frac{n_1}{n_2}$ |
|---|---|---|---|---|
| | Kremsmünster | Freiburg | Rothhorn | |
| 0– 50 | .... | 1.12 | .... | .... |
| 50–100 | 1.14 | 1.31 | .... | 1.11 |
| 100–150 | 1.24 | 1.69 | .... | 1.15 |
| 150–200 | 1.48 | 1.84 | .... | 1.28 |
| 200–300 | .... | .... | 3.21 | 1.42 |
| 300–400 | .... | .... | 4.33 | .... |
| 400–500 | .... | .... | 5.46 | .... |
| 500–700 | .... | .... | 8.75 | .... |

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THE VALUE OF $\frac{n_1+n_2}{2N}$, N BEING THE NUMBER OF IONS PER C. C. PRESENT IN THE STEADY STATE, AND IN THE ABSENCE OF THE ELECTRIC FIELD.

From (25)

$$(n_1+n_2)\,ev = 2\,ev\sqrt{\frac{q}{a}}\frac{X_0}{X}(1-\epsilon)^{1/2}$$

But since $\sqrt{\frac{q}{a}} = N$

$$\frac{n_1+n_2}{2N} = \frac{X_0}{X}(1-\epsilon)^{1/2} \tag{27}$$

For the case of the atmosphere, where $\epsilon = 0$

$$\frac{n_1+n_2}{2N} = \frac{X_0}{X} \tag{28}$$

so that, since $\frac{X_0}{X}$ is always less than unity, $n_1 + n_2$ is less than $2N$. This is not entirely due to the deficit in the negative ions, for near the surface, where $n_2 = 0$, (28) becomes

$$\frac{n_1}{N} = 2\frac{X_0}{X_1}$$

and we have seen that $\frac{X_1}{X_0} = 2.766$ ; accordingly

$$\frac{N}{n_1} = 1.383 \ .$$

Hence the number of positive ions *as well as* the number of negative ions is less than the number $N$ corresponding to the equilibrium state given by $q = a\,N^2$.

At a height of about 3.5 meters, where (see Table IV) $\frac{X}{X_0} = 1.603$ for a field of 100 volts/meter, (28) gives

$$\frac{2N}{n_1+n_2} = 1.603$$

Again, from Table IV, $\frac{n_1}{n_2} = 2.12$, hence $n_2 = 0.400N$ and $n_1 = 0.848N$ .

It will be obvious that, in so far as the measured value of the mean conductivity for positive and negative ions is proportional to $n_1 + n_2$, this quantity should be proportional to $\frac{X_0}{X}$, and so for a given height should decrease with increase of $X_0$ (see Table III). The ratio of the positive to the negative conductivity should of course increase with $X_0$. It may be noted that, owing to the defi-

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cit in the number of positive and negative ions, we must not calculate the rate of formation $q$ from the formula $q = \alpha n_1 n_2$, where $n_1$ and $n_2$ are the *measured* number of ions. We must use $q = \alpha N^2$, which, in the case of the above example, would be equivalent to writing

$$q = \alpha \frac{n_1 n_2}{0.34}$$

Thus, if we used the formula $q = \alpha n_1 n_2$, the value of $q$ we should calculate would be only 0.34 of the true value.

## Apparent Variation of $q$ with the Height.

We have seen that

$$\frac{n_1 + n_2}{2N} = \frac{X_0}{X} \tag{29}$$

and

$$n_1 - n_2 = \frac{1}{4\pi e}\left(\frac{dX}{dx}\right) \tag{30}$$

Hence,

$$n_1 n_2 = \left(N\frac{X_0}{X}\right)^2 \left\{1 - \left(\frac{X}{8\pi e N X_0}\frac{dX}{dx}\right)^2\right\}$$

Now, since $\frac{X_0}{X}$ increases with the height and $\frac{dX}{dx}$ diminishes with the height, $n_1 n_2$ increases with the height, hence, if $q$ is deduced from the relation $q = \alpha n_1 n_2$, an apparent increase of $q$ with the height will be found.

It is worth while freeing this conclusion from as many of the assumptions as render our theory of limited application to a special kind of atmosphere. With this purpose in view, we observe that (30) is true universally, provided that the value of $\frac{dX}{dx}$ appropriate to the point be put in. The equation

$$i = (n_1 v_1 + n_2 v_2) e X \tag{31}$$

is also universally true, and since $i$ is constant, we may write

$$(n_1 v_1 + n_2 v_2) X = (\bar{n}_1 \bar{v}_1 + \bar{n}_2 \bar{v}_2) \bar{X} \tag{32}$$

where the letters with a bar refer to values at some point higher than that to which the other letters refer.

From (30) and (32) we find

$$n_1 n_2 = \left\{\frac{\bar{n}_1 \bar{v}_1 + \bar{n}_2 \bar{v}_2}{v_1 + v_2}\right\}^2 \left(\frac{\bar{X}}{X}\right)^2 \left\{1 + \frac{v_2 - v_1}{4\pi e (\bar{n}_1 \bar{v}_1 + \bar{n}_2 \bar{v}_2)} \frac{X}{\bar{X}} \frac{dX}{dx} - \frac{v_2 v_1}{16\pi^2 e^2 (\bar{n}_1 \bar{v}_1 + \bar{n}_2 \bar{v}_2)^2}\left(\frac{X}{\bar{X}}\frac{dX}{dx}\right)^2\right\} \tag{33}$$

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Suppose, to fix our ideas, we imagine that the point to which $\overline{X}$ refers is, say, 10 meters above that to which $X$ refers. From balloon experiments it has been found that the relationship between $X$ and the height, $h$, may be expressed empirically in the form[4]

$$X = \frac{34}{30000} - \frac{0.00006h}{30000} \tag{34}$$

and this expression will, at any rate, serve to give us the order of magnitude of $\frac{dX}{dx}$. If then we substitute in (33) quantities of the order of magnitude of the quantities involved, we shall find that the main factor determining the variation of the expression with the height is the external factor $\left(\frac{\overline{X}}{X}\right)^2$. In fact, we may write approximately

$$n_1 n_2 = \left\{\frac{\overline{n}_1\overline{v}_1 + \overline{n}_2\overline{v}_2}{v_1 + v_2}\right\}^2 \left(\frac{\overline{X}}{X}\right)^2 \tag{35}$$

which tells us that, unless $v_1 + v_2$ increases so much with the height as to mask the effect, which can be shown not to be the case in practice, $n_1 n_2$ increases with the height, since $\frac{\overline{X}}{X}$ increases with the height, and consequently if we erroneously calculate $q$ from $q = \alpha\, n_1 n_2$, we shall obtain an apparent increase of $q$ with the altitude. If we write $q' = \alpha\, n_1 n_2$ where we may call $q'$ the apparent rate of formation, we find, from (35)

$$\frac{1}{q'}\frac{d\,q'}{d\,h} = -\frac{2}{X}\frac{d\,X}{d\,h} - \frac{2}{v_1 + v_2}\frac{d\,(v_1 + v_2)}{d\,h} \tag{36}$$

The result will hold quite generally, no matter how the pressure, true rate of formation ($q$) of ions, etc., vary with the height, provided that we put in the true value of the quantities $\frac{dX}{dh}$, etc., appropriate to the point in question. Making use of (34), we find, from (36), that $\frac{2}{X}\frac{dX}{dh} = 0.00012/34$, *i. e.*, $q'$ should change by a quantity of the order 0.036 per cent. per meter rise.

It must be noted that the expression for the percentage variation of $n_1 n_2$ with the height is quite independent of the true rate of formation of ions, and of its variation with the height, except in so far as that quantity determines the field distribution. It is the field distribution which is the fundamental factor in determining the variation of $q'$ with the height. The variation of $q'$ alters, as

[4] See article by C. CHREE, *Encyclopædia Britann a*, 11th edition.

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it were, automatically with the field distribution, and, as we have said, is only affected by $q$ in so far as that quantity is one of the factors determining the field distribution, the other factors being the specific velocities of the ions. Thus, there is no simple relation between $q$ and $q'$, that is to say, no exact information as to the true variation of the rate of formation with the height can be drawn from the variation of the apparent rate of formation.

### Case of Two Plates Separated by a Comparatively Small Distance.

Though this case has no special cosmical interest, it may be worth while stating a few points in relation to the application of the foregoing conclusion to it.

We have seen that when $q = 11$ and $X_0 = 100$ volts per meter, the field would be practically uniform between the plates when the latter are 14 cm. apart. In fact, for this case we had $\epsilon = 0.999$, and

$$\frac{X_1}{X_0} = 1.0026$$

Since $\frac{X}{X_0}$ is practically unity at all points, (25) becomes

$$n_1 + n_2 = 2\sqrt{\frac{q}{a}}(1-\epsilon)^{\frac{1}{2}}$$

and since $\sqrt{\frac{q}{a}} = N$

$$n_1 + n_2 = 2N\sqrt{0.001}$$

Thus the number of ions would only be about $\frac{1}{30}$ of the normal number ($2N$), hence the uniformity of the field does not carry with it obedience to the law which gives the relation between the current and field for cases where $q$ is much larger.

### CONCLUSION.

We have thus seen that the mere assumption that there is an electrostatic field at all, carries with it qualitatively the necessity of the laws stated on the first page of this paper.

In view of the restrictions which we have had to make in many cases, such as the assumption of the equality of the velocity of the positive and negative ions and the constancy of $q$ with the height, it is, perhaps, too much to expect a perfect quantitative agree-

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ment between theory and experiment, but it is interesting to notice that the values calculated, such as the ratio $\frac{n_1}{n_2}$, are of the right order of magnitude, so that one cannot help but feel that the physical principles underlying the explanation of the facts are those contained in the present theory.

There are many ways in which a slight modification of the conditions would be accompanied by a considerable change in the magnitude of the quantities involved. For example, the assumption of a fairly intensely ionized layer in the immediate vicinity of the ground would result in $n_2$ not being zero there, which would tend to reduce the sharpness of the change in the potential gradient near the ground.

Perhaps one of the most interesting results of the theory is the suggestions which it gives for further experiment. For instance, the theory in its present form requires a sharp variation of the potential gradient in the immediate neighborhood of the ground, and a similar remark applies to the ratio $\frac{n_1}{n_2}$. The difficulty of *calculating* numerically the variation of $X$ with the height lies in the uncertainty of our knowledge of the distribution of $X$, $q$, etc., with the height, the conditions holding at the surface, etc., but it is to be noted that the equations (30) and (32) are *universally* true, and from them we can get a large amount of information with regard to the theoretical variation of $\frac{n_1}{n_2}$, $n_1 + n_2$, $n_1 n_2$, with the height, provided that we know even empirically the variation of $X$ with the height. Thus, an accurate experimental knowledge of this quantity would be of great service as a basis for such calculations. Measurements of $n_1$ and $n_2$ taken at different heights simultaneously with measurements of the potential gradient would be of great value as forming a check on the theory connecting them.

It will be noticed that according to the theory a reversed potential gradient would result in $\frac{n_1}{n_2}$ becoming less than unity. A corresponding remark would apply in a less degree to the ratio of the dispersion coefficients. The quantities $n_1$ and $n_2$ should, however, still increase with the height. It would be interesting to test the truth of the above conclusion when the reversed potential gradient was accompanied by conditions sufficiently steady to render this possible.

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It will be realized that the rapid variation of the potential gradient which the theory predicts in the neighborhood of the ground is intimately bound up with the abnormality in the number of positive and negative ions there. Slight disturbing causes, such as draught, etc., will consequently have great influence on these quantities when measured near the ground. On the other hand, if we go several meters up, disturbing causes will have less effect, for even though the disturbances were so great as to correspond to a bodily movement of the Earth upward through a meter or so, very little effect would be produced on the quantities measured. In fact, the field near the ground is largely controlled by the adjustment which it has to make in itself in order to conform to the surface conditions, and it is thus liable to large fluctuations. The field higher up (say 50-100 meters) is controlled more completely by the phenomena of more purely cosmical interest which are responsible for the existence of the field. It would consequently be worth considering the advisability of making atmospheric electricity measurements well above the surface, when the primary object is the detemination of diurnal variation, etc.

In conclusion, it must be remarked that the whole of the foregoing argument is based on the assumption that the steady state has been attained in the atmosphere, *i. e.*, that the current density is independent of the height. In view of the very large fluctuations to which the potential gradient is subject in a short time, this assumption may be open to some question, but experiments, as far as they have gone have apparently shown very little variation of the current density with the height.

I should like to express my thanks to Mr. C. R. Duvall for the pains he has taken in the verification of the mathematical and of the numerical work.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
*November 19, 1913.*

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# A NEW UNIVERSAL MAGNETIC THEODOLITE FOR DETERMINING THE DECLINATION, AND THE HORIZONTAL AND VERTICAL INTENSITIES.

By N. Ogloblinsky,
*Superintendent of Compasses, R. I. Navy.*

Ten years ago it occurred to me to apply some of the principles underlying the determination of the magnetic forces on board, adopted in the Russian Imperial Navy, to the direct measurement of the horizontal intensity $H$ and the vertical intensity $Z$, with land instruments. Accordingly, in 1909 there were prepared the designs of a new theodolite for the determination of $H$ and $Z$ as well as of the declination, $D$, and for astronomical work. During the years 1910 and 1911 the instrument was constructed in the workshops of the General Hydrographic Office under the supervision of the chief of the shops, Mr. Heinrich Freiberg, the well-known mechanician and collaborator of the late Heinrich Wild.

The first tests of the new theodolite in Pavlovsk at the Constantin Observatory in 1911 and especially in a magnetic survey along the shores of the Bay of Finland, near Cronstadt in 1912, under severe conditions, gave satisfactory results. I was thus led to think that the proposed method might be applied to advantage in land magnetic survey work and even in observatory work.

The principle of the method, in a somewhat different form, was used during about thirty years in the Imperial Russian Navy for finding the horizontal and vertical magnetic forces acting on the compass needle, and is due to the late Professor General de Collongue. In the new theodolite, the disposition of the magnet is different from that in the Collongue's deflector and, instead of one, two magnets, one on each side of the suspended needle system, are used. This, at first sight, seeming complication affords the following advantages: It permits the use of shorter magnets and makes the series for $\frac{H}{M}$ and $\frac{Z}{M}$ more convergent; it abolishes the necessity of transporting the magnet from one side of the needle-system to the other and, what is most essential for field-work, makes the measurements nearly independent of changes in the position of the deflected needles up to about $\pm \frac{1}{2}$ mm along the line, joining the centers of the magnets. The advantage of using in deflections two magnets, instead of one, was pointed out by



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Lord Kelvin; this idea, it seems, was first realized, in the Physical Laboratory of the University of Glasgow, by Professor Thomas Gray in 1885.

The principle for the measurement of the horizontal intensities by means of the new theodolite is as follows:

Let us place along the magnetic meridian, in the same horizontal line $OM$ (Fig. 1a), the magnetic axes of two magnets $A$ and $B$, each fixed on a separate and movable sliding rod, forming the part of a system; by means of this rod, the magnets $A$ and $B$ may be moved along the meridian and placed at equal distances from the center $O$, of the instrument; each magnet can be turned by 180° around axes $rr$, $r'r'$, passing through the centers of the magnets $A$ and $B$; the distance between the centers $A$ and $B$ is read on a millimeter scale on the side of each rod. In the center, $O$, is suspended, on a silk fiber, a light system of six horizontal needles $ns$, $n's'$ with a small plane mirror, perpendicular to the needles; the system is free to turn round the vertical axis $KO$. To the tube, in which the fiber hangs, is fastened an auxiliary magnet, $PQ$, whose magnetic axis is horizontal and perpendicular to the vertical plane, passing through the centers of the magnets $A$ and $B$; it is evidently perpendicular to the meridian, when the magnets $A$ and $B$ are placed along it.

*By bringing the magnets A and B nearer or farther from the center of the needles, there can be found such a distance between the centers of the magnets, equal, let us say, to* $2R_0'$, *that the needles ns,* $n's'$ *will be deflected at right angles to the meridian and will be therefore parallel to the auxiliary magnet PQ.*

Let us denote the distances $AO$ and $BO$ (Fig. 1a) by $R_A$ and $R_B$, respectively, so that $R_A + R_B = 2\,R_0'$, and let $2R_0$ be the mean of the readings of the distance on the scales, when the magnets are at the distance $2R_0'$; by adjustment of the instrument $2R_0$ is the length $2R_0'$, reduced to 15° C. Further denote by $M_{15}$ the sum of the magnetic moments of $A$ and $B$ at 15° C. or $M_{15} = M_A + M_B$; by $H$, the horizontal intensity; by $\nu_1$, the coefficient of induction from $H$ and from reciprocal induction of the magnets $A$ and $B$; by $\mu$, the mean temperature coefficient of $A$ and $B$, and by $\sigma$, the expansion coefficient (linear) of the rod. Put $\Delta\tau_H = t_H - 15°$ where $t_H$ is the temperature of the rods and the magnets $A$ and $B$. Then from the condition of equilibrium, we will find:

$$\frac{H}{2M_{15}} = \frac{1}{R_0^3}\left[1 + \frac{\omega}{R_0^2}\right]\left\{1 - \nu_1 H - \mu_1 \Delta\tau_H\right\} \qquad (1)$$

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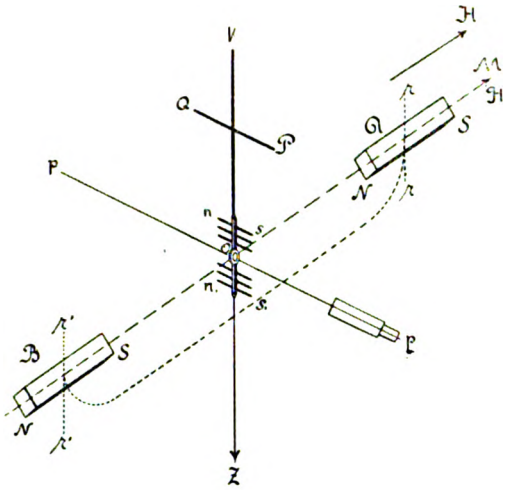


FIG. 1a.

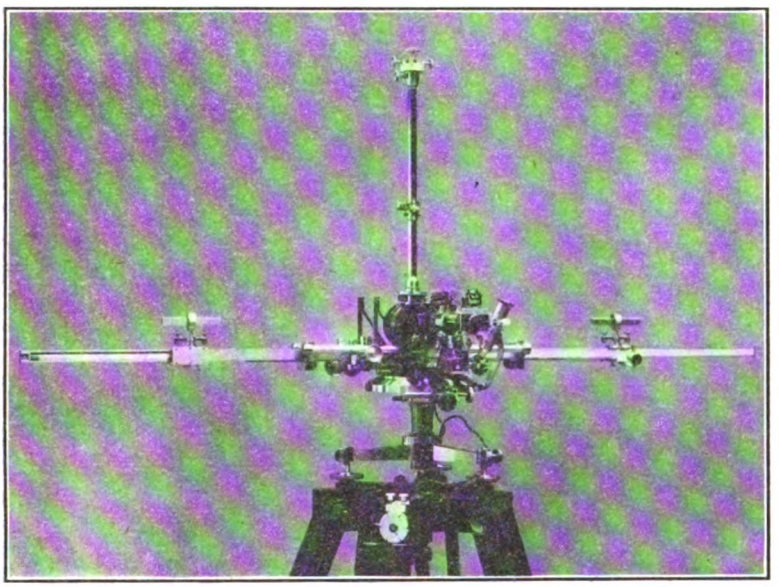

FIG. 1b.

HORIZONTAL INTENSITY DETERMINATION.



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Here $\omega$ is the distribution coefficient; for the dimensions of magnets and needles adopted in the theodolite, the term with $\frac{1}{R_0^4}$ may be omitted. Fig. 1b shows the instrument as arranged for the determination of $H$.

Now let us set up the system of sliding rods with the magnets fixed to them in the *vertical* position, and let us suspend on the threads $Ka$ and $Kb$, as shown in Fig. 2a, in the center, $O$, of the instrument, a system of needles $ns$, $n's'$, identical to the preceding needle-system. The threads must be arranged so that the axis of rotation of the needles should be horizontal, and let us place them perpendicular to the meridian $OM$ (or nearly so); the needles will swing in the plane of the magnetic meridian. It is easy to see, that the relative position of magnets and needles will be the same, as in the former case, only there the system of rods was horizontal, and needles vertical, and here the rods are vertical and needles horizontal. Suppose, now, that the center of gravity of the needles coincides with the axis of rotation $ab$ and that there is no torsion of the threads.

*The measurement of the vertical intensity will consist in bringing the centers of the magnets A and B to such a distance, that the needles will occupy a horizontal position, along the component H;* the latter in this case plays the same rôle as the auxiliary magnet $PQ$ (Fig. 1b) in the former measurement.

Let $Z$ be the vertical intensity, let $R'_A$, $R'_B$ and $2R'_1$, be the corresponding vertical distances of the magnets $A$ and $B$ from the center $O$ and from each other, where $2R'_1 = R'_A + R'_B$. Let $2R_1$ be the mean of the readings of the scales, which is equal to the length $2R'_1$, reduced to 15° C. If we denote by $\Delta\tau_z = t_z - 15°$, where $t_z$ is the temperature of the rods (and magnets); by $\nu_1$, $\mu_1$ $\omega_1$ the same coefficients, as in the first measurement, the numerical value of the coefficient $\omega_1$ being slightly different from $\omega_1$ we will find:

$$\frac{Z}{2M_{15}} = \frac{1}{R_1^3}\left[1 + \frac{\omega_1}{R_1^2}\right]\left\{1 - \nu_1 Z - \mu_1 \Delta\tau_z\right\} \qquad (2)$$

Both formulæ (1) and (2) follow from more complicated expressions, but for brevity's sake only the final results are here given. Fig. 2b shows the instrument as arranged for the determination of the vertical intensity.

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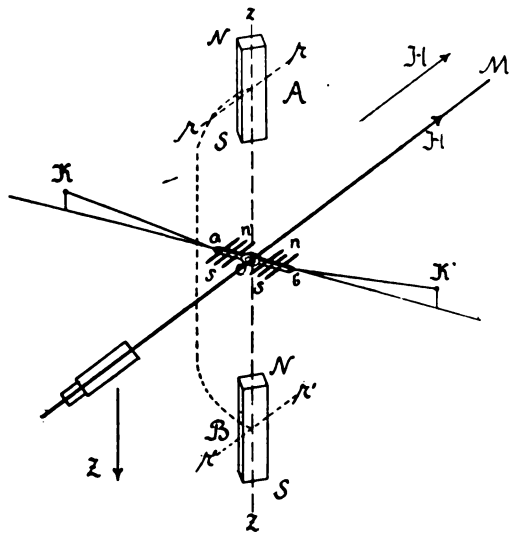


FIG. 2a.

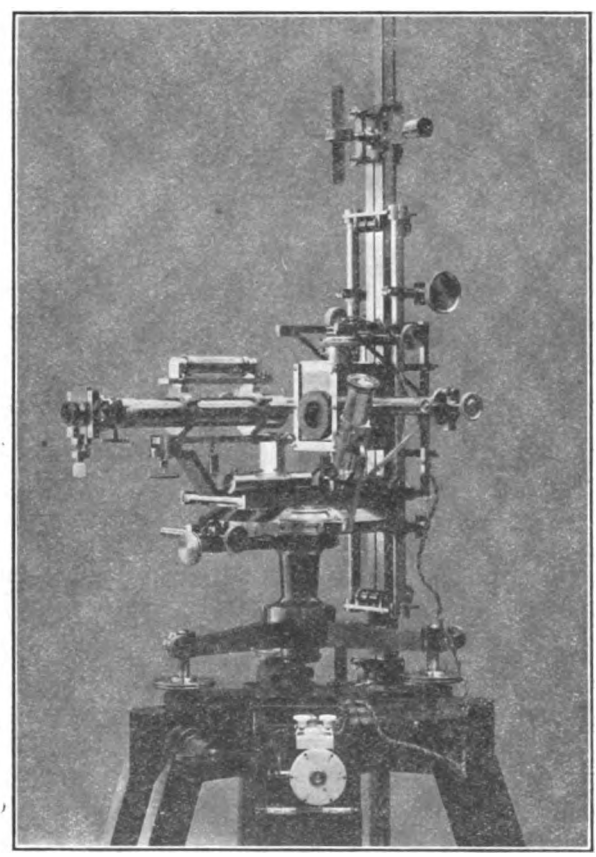

FIG. 2b.

VERTICAL INTENSITY DETERMINATION.



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From the preceding it follows that the data for finding the components $H$ and $Z$ or, more strictly, the ratios $\frac{H}{2M}$ and $\frac{Z}{2M}$ are the two distances $R_0$ and $R_1$. In the new theodolite they are found doubled; the readings on the scales give the distances $2R_0$ or $2R_1$, within $\pm$ 0.02 mm. and less; as the least distance $AB = 2R$ in the instrument is about 37 cm. and as the constant errors can be known to within few microns, the measurement of distances with the error, less than $\pm 1/18500\ R$ is obtained quite easily.

The magnetic moment $M_{15}$ is equal to about 2200 units C. G. S.; as the magnets may be placed at the distances $2R$ from 80 cm. to 37 cm. and $\omega$ being about 10.5, the theodolite permits measuring directly intensities ranging from 0.007 to 0.730 C. G. S.

For finding $H$, $2M_{15}$ and $Z$ in absolute units, it remains to swing in turn both magnets $A$ and $B$ for determining the periods of vibration $T_A$, $T_B$ and the product $2H\ (M_A + M_B) = 2M_{15}H$.

To obtain the ratios $\frac{H}{2M_{15}}$ and $\frac{Z}{2M_{15}}$, we must calculate the quantities:

$$F_H = \frac{1}{R_0^3}\left[1 + \frac{\omega}{R_0^2}\right];\ F_Z = \frac{1}{R_1^3}\left[1 + \frac{\omega_1}{R_1^2}\right] \qquad (3)$$

but they can be found directly with the arguments $R_0$ or $R_1$ from a suitable table, specially calculated for this theodolite.

To realize exactly the theoretical conditions for the disposition of the magnets, needles and rods would be very difficult; the errors in measurement $\frac{H}{2M}$ and $\frac{Z}{2M}$, due to instrumental and other errors, are, accordingly eliminated by proper arrangement of observations.

The quantity $2M_{15}H$, for each magnet, is found by the usual method of observation of the periods of oscillation $T_A$ and $T_B$. For this purpose a special instrument is provided which is used at the same time also for determination of declination. Both magnets, for swinging, are screwed in the special stirrup always in the same position relatively to the axis of rotation.

For each oscillation, the usual formula is applied, but as we have two magnets, the expression for $\sqrt{2M_{15}H}$ will not be the logarithmic one; but by a simple transformation this difficulty can be avoided.

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The moments of inertia of the oscillating system with the magnet $A = I_A$, and with the magnet $B = I_B$ are supposed to be determined at an observatory. In the field, in case of need, the observer is enabled to make the oscillations with ring mounted on the magnet without any trouble by simply lowering the ring to the stirrup, above which the ring is always fastened.

The advantages of the new theodolite, as they appear to me, may be briefly summarized as follows:

1. The elements $H$ and $Z$, or more precisely, the quantities $\frac{H}{M}$ and $\frac{Z}{M}$, $M$ being the magnetic moment, are measured directly in the same units and are determined, each, by means of only *four readings* on an ordinary millimeter scale (excepting the thermometer readings); these four readings give *two* independent values for the element measured, and thus the observer has at once the control of his work.

2. The change in the direction of the magnetic field during the observation of $H$ or the movement of the instrument itself in azimuth within 30′ to 40′, has no influence on the accuracy of the measured values. The determination of $Z$ is independent of the changes in the intensity of $H$.

The measurements of $\frac{H}{M}$ and $\frac{Z}{M}$ are also practically *independent of the small variations in the distance of the deflected magnet or needles* (within 0.2 to 0.3 mm.) from the center of the theodolite or from the deflecting magnets.

3. The reduction of the observed values to a selected epoch is much simplified; only four $H$ and four $Z$ values, simultaneous to the readings on the scale of the theodolite, are necessary for correcting $\frac{H}{M}$ and $\frac{Z}{M}$.

The full description of the new universal theodolite, its concise theory and the results of the first tests have just appeared in Russia.[1] A specimen of the determination $\frac{Z}{M}$ and $\frac{H}{M}$ follows, $Z/M$ being observed twice.

[1] OGLOBLINSKY, N. A new universal theodolite for determining the terrestrial magnetic elements. [Russian text.] St. Petersburg, 1913 (123 with 6 pl.). 25 cm.

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## SPECIMEN OF OBSERVATION

*Station:* Cronstadt, Petrovsky Park. *Date:* Aug. 27, 1912.

*Circle reading of the meridian:* 299° 1′30″

### Vertical Intensity.

| Time | Scale | Position of the Magnets | Observer | Level | T | | Results |
|---|---|---|---|---|---|---|---|
| h m s | | | | | ° | | |
| 10 38 20 | 430.24 | II up | on S | right | +14.8<br>14.9 | a | ½ (a + c) = $Z_1$ = 430.32 |
| 10 41 25 | 429.98 | I up | on S | right | +15.0<br>14.7 | b | ½ (b + d) = $Z_2$ = 430.29 |
| | | | | | | | Mean..... 430.30 |
| Polarity of Needles Reversed. | | | | | | | Hence |
| 10 45 35 | 430.40 | I up | on N | right | +14.8<br>15.0 | c | calculated Z = 0.46857 C. G. S. |
| 10 49 10 | 430.60 | II up | on N | right | +14.7<br>14.9 | d | |
| Vertical Intensity Repeated. | | | | | | | |
| h m s | | | | | ° | | |
| 10 50 50 | 430.58 | II up | on N | right | +14.7<br>14.9 | a | ½ (a + c) = $Z_1$ = 430.35 |
| 10 53 30 | 430.23 | I up | on N | right | +14.7<br>15.0 | b | ½ (b + d) = $Z_2$ = 430.31 |
| | | | | | | | Mean..... 430.33 |
| Polarity of Needles Reversed. | | | | | | | Hence |
| 10 58 25 | 430.12 | I up | on S | right | +14.7<br>15.0 | c | calculated Z = 0.46846 C. G. S. |
| 11 1 45 | 430.39 | II up | on S | right | +15.1<br>15.0 | d | |

### Horizontal Intensity.

| Circle | Time | Scale | T | Results |
|---|---|---|---|---|
| ° ′ | h m s | | ° | |
| 209 01 | 11 07 40 | 610.33<br>.35 | +15.3<br>15.4 | calculated |
| 29 01 | 11 12 25 | 609.82<br>.84 | +15.5<br>15.4 | $H$ = 0.16234 C. G. S. |
| 29 01 | 11 14 10 | 609.82<br>.84 | +15.5<br>15.5 | |
| 209 01 | 11 18 40 | 610.31<br>.33 | +15.5<br>15.4 | Magnetic moment $2M_{15}$ = 2283.9 C. G. S. is taken from other determination on the same day. |
| | Mean..... | 610 08 | | |

St. Petersburg, Admiralty.



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# PRACTICAL PROCESSES FOR PRODUCING THE BEST PERMANENT MAGNETS.[1]

By Silvanus P. Thompson.

To produce permanent magnets, which are both powerful and constant in their power, a tungsten steel should be used having from 5 to 8 per cent of tungsten, and from 0.4 to 0.6 of carbon. Chromium up to 2 or 2.5 per cent may be present, but the presence of the following elements should be avoided: manganese, titanium, copper, sulphur, and phosphorus.

For bar magnets there is an advantage in having the dimension-ratio as large as possible, as this gives not only a higher remanence, but a lower coefficient of temperature variation. For horse-shoe magnets, and for all those which are to be used in instruments where extreme constancy is required, the gap between the poles should be as short as possible, and the polar areas should be as large as possible. From the point of view of constancy there is an advantage in having a considerable stray flux (through a magnetic shunt or otherwise) in addition to the useful flux.

The forging of the magnet, whether bar or horse-shoe, should be done with as little working of the material as possible, and at as low a temperature as is convenient. After forging, to normalize the material it should be heated to 900° C., lowered to 750° C., and there maintained for a time, then cooled off. To harden the magnets, they should be raised to 950° C. for a period not exceeding 5 minutes; and then lowered to about 700° C., and quenched at this temperature in brine, or at a temperature under 20° C. Some brands of high tungsten steel appear to yield a better result if quenched at some temperature between 770° and 850° C., or even at higher temperatures.

With tungsten steels there appears to be no advantage whatever in tempering the steel. With carbon steels there is no advantage in tempering the magnet if it is one having a small dimension-ratio (as for short bars). But bar magnets of carbon steel, if their length is as much at 20 diameters, may be tempered to a straw tint, or if as much as 40 diameters long, or more, they may be let down to a blue tint, and will then receive more magnetism. Any letting down below a straw tint, however, impairs their power to resist decay and usage.

The magnets should then be matured either by boiling or steaming them for ten or twelve hours, or by heating them to 60° C. for 20 or

[1] Extracted from "The Magnetism of Permanent Magnets," by Silvanus P. Thompson. Reprint from *Journal of Institution of Electrical Engineers*, 1913, Part 217, Vol. 50, pp. 80–142.



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more hours. There is some advantage in letting them cool several times during this process. For a magnet that is intended to be used at some particular temperature, and is required to be as constant as possible at that temperature, there is some advantage in subjecting it to a number of cyclic processes of alternately heating it to a few degrees above, and cooling it to a few degrees below, that temperature at which it is intended thereafter to be used.

The magnet should then be magnetized by means of an electromagnet, or, if a bar magnet, in a powerful magnetizing coil, to the highest degree of magnetization possible. There is some advantage in reversing its magnetism a few times. There is no advantage in magnetizing for a long time, as the result depends on the maximum magnetizing force applied, and not on the duration of the application. But in the final magnetization the magnetizing current should not be suddenly switched off, but should be diminished gradually to zero. There appears to be a slight advantage in subjecting the magnet during magnetization to mechanical percussion, by striking it with a hammer of brass or other non-magnetic hard material.

For magnets that are to be given extreme constancy there is an advantage in then slightly reducing their magnetism by subjecting them to demagnetizing forces, a reduction of from 5 to 10 per cent being sufficient. It is doubtful whether this process is necessary[2] for magnets the form of which is a closed circuit with a very narrow gap.

Just as the thermal stability of a magnet is best assured by subjecting it to small cycles of heating and cooling about the point of temperature at which it is thereafter to be used, so its magnetic stability is best assured by subjecting it to small cycles of demagnetizing and remagnetizing force about the point of magnetization at which its magnetism is thereafter to remain constant. It would, indeed, be advantageous to repeat this small cycle several times over, so as to bring the magnetic state into a final condition, where the effects of any accidental external magnetic influences will be a minimum.

[2] Mr. George Hookham kindly informs me that for meter magnets the firm of Chamberlain and Hookham do not resort to partial demagnetization. "We flash our magnets," he says, "to saturation, and never think of reducing them, and find them sensibly permanent—that is, if they have only the air-space to deal with. If they have other reversing influences to contend with, as in alternating-current meters, then we may reduce them."

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# *LETTERS TO EDITOR*

## MAGNETIC RESULTS AT PILAR AND LAURIE ISLAND, ORCADAS DEL SUR, 1905–1912.

In the following summaries of magnetic results at Pilar and Laurie Island, Orcadas del Sur, the means are derived from all hours including disturbed days. The Orcadas data are derived from the variometer records: the numerous gaps show that we have been unfortunate with that station up to the past two years, owing to the breaking down of the register clocks and the inexperience of the observers. The absolute observations for the station are much more complete, but it would be most laborious to abstract results from them; however, a fair idea of the secular variation may be obtained from the present data.

L. G. SCHULTZ.

*Oficina Meteorológica Argentina Observatorio Magnético, Pilar, F. C. C. A., Provincia de Córdoba.*

TABLE I. *Mean annual values of the magnetic elements at Pilar, 1905 to 1912. Latitude:* 31° 40′ S.; *longitude:* 63° 53′ W.

| Year | Declination | Inclination | Horizontal Intensity | Vertical Intensity |
|---|---|---|---|---|
| | ° ′ | ° ′ | γ | γ |
| 1905[1] | 9 51.6E | 26 02.9S | 25912 | 12665 |
| 1906 | 9 45.0E | 26 01.0S | 25870 | 12627 |
| 1907 | 9 38.1E | 26 00.8S | 25824 | 12602 |
| 1908 | 9 29.1E | 25 57.2S | 25810 | 12563 |
| 1909 | 9 21.6E | 25 55.8S | 25762 | 12526 |
| 1910 | 9 13.9E | 25 52.8S | 25712 | 12474 |
| 1911 | 9 05.4E | 25 49.4S | 25699 | 12436 |
| 1912 | 8 57.1E | 25 45.0S | 25682 | 12388 |

TABLE II. *Mean monthly values of the magnetic declination at Pilar, July, 1904, to December, 1912.*

(*D* is East.)

| Month | 1904 | 1905 | 1906 | 1907 | 1908 | 1909 | 1910 | 1911 | 1912 |
|---|---|---|---|---|---|---|---|---|---|
| | E 9°+ | 9°+ | 9°+ | 9°+ | 9°+ | 9°+ | 9°+ | 9°+ | 8°+ |
| | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| January | .... | .... | 48.3 | 42.3 | 33.8 | 25.7 | 17.6 | 09.2 | 60.8 |
| February | .... | 54.0 | 47.4 | 41.7 | 33.0 | 25.1 | 16.8 | 08.5 | 59.8 |
| March | .... | 53.9 | 46.9 | 40.1 | 31.2 | 24.0 | 16.5 | 08.0 | 58.9 |
| April | .... | 53.0 | 46.2 | 39.2 | 30.5 | 22.8 | 15.9 | 07.3 | 58.7 |
| May | .... | 52.1 | 45.6 | 38.5 | 29.6 | 22.3 | 15.2 | 06.2 | 57.8 |
| June | .... | 51.7 | 45.4 | 38.2 | 28.8 | 21.2 | 14.2 | 05.7 | 56.9 |
| July | 57.9 | 51.1 | 44.8 | 37.4 | 28.2 | 20.8 | 13.1 | 05.1 | 56.4 |
| August | 56.5 | 50.9 | 44.3 | 37.4 | 27.8 | 20.4 | 13.2 | 04.6 | 56.5 |
| September | 55.7 | 50.5 | 43.6 | 36.9 | 27.9 | 20.3 | 11.9 | 03.2 | 55.8 |
| October | 55.3 | 49.4 | 42.8 | 36.0 | 26.6 | 20.6 | 11.4 | 02.7 | 54.8 |
| November | 54.9 | 49.9 | 42.4 | 35.2 | 26.4 | 18.9 | 10.8 | 02.1 | 54.6 |
| December | .... | 48.9 | 41.9 | 34.5 | 25.4 | 18.3 | 09.8 | 01.6 | 54.0 |
| Mean | .... | 51.6 | 45.0 | 38.1 | 29.1 | 21.6 | 13.9 | 05.4 | 57.1 |

[1] Data for January missing.



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TABLE III. *Mean monthly values of the horizontal intensity at Pilar, July, 1904, to December, 1912.*

[$H$ = 25000 $\gamma$ +]

| Month | 1904 | 1905 | 1906 | 1907 | 1908 | 1909 | 1910 | 1911 | 1912 |
|---|---|---|---|---|---|---|---|---|---|
| | $\gamma$ | $\gamma$ | $\gamma$ | $\gamma$ | $\gamma$ | $\gamma$ | $\gamma$ | $\gamma$ | $\gamma$ |
| January | ... | ... | 907 | 849 | 832 | 791 | 732 | 708 | 696 |
| February | ... | 926 | 882 | 820 | 828 | 783 | 730 | 703 | 699 |
| March | ... | 922 | 876 | 830 | 809 | 772 | 715 | 705 | 690 |
| April | ... | 916 | 874 | 832 | 819 | 778 | 707 | 698 | 687 |
| May | ... | 919 | 865 | 819 | 814 | 758 | 704 | 696 | 679 |
| June | ... | 912 | 874 | 819 | 819 | 770 | 711 | 699 | 679 |
| July | 968 | 912 | 867 | 816 | 817 | 767 | 713 | 697 | 679 |
| August | 940 | 906 | 858 | 822 | 807 | 765 | 711 | 695 | 674 |
| September | 937 | 901 | 853 | 808 | 783 | 744 | 712 | 696 | 673 |
| October | 930 | 911 | 854 | 825 | 795 | 722 | 698 | 695 | 676 |
| November | ... | 898 | 870 | 826 | 793 | 750 | 708 | 699 | 676 |
| December | ... | 912 | 857 | 832 | 805 | 749 | 708 | 694 | 677 |
| Mean | ... | 912 | 870 | 824 | 810 | 762 | 712 | 699 | 682 |

TABLE IV. *Mean monthly values of the vertical intensity at Pilar, July, 1904, to December, 1912.*

[$Z$ = 12000 $\gamma$ +]

| Month | 1904 | 1905 | 1906 | 1907 | 1908 | 1909 | 1910 | 1911 | 1912 |
|---|---|---|---|---|---|---|---|---|---|
| | $\gamma$ | $\gamma$ | $\gamma$ | $\gamma$ | $\gamma$ | $\gamma$ | $\gamma$ | $\gamma$ | $\gamma$ |
| January | ... | ... | 637 | 612 | 575 | 543 | 496 | 460 | 410 |
| February | ... | 690 | 637 | 613 | 579 | 545 | 496 | 461 | 403 |
| March | ... | 681 | 629 | 610 | 574 | 542 | 486 | 452 | 399 |
| April | ... | 670 | 628 | 610 | 569 | 544 | 482 | 444 | 401 |
| May | ... | 675 | 631 | 610 | 571 | 545 | 480 | 443 | 398 |
| June | ... | 672 | 632 | 603 | 566 | 534 | 473 | 438 | 395 |
| July | 700 | 664 | 629 | 602 | 564 | 526 | 468 | 435 | 389 |
| August | 691 | 667 | 627 | 601 | 559 | 515 | 470 | 430 | 386 |
| September | 690 | 658 | 625 | 596 | 554 | 509 | 463 | 424 | 379 |
| October | 692 | 646 | 619 | 592 | 550 | 511 | 461 | 419 | 373 |
| November | ... | 646 | 619 | 590 | 549 | 497 | 461 | 415 | 365 |
| December | ... | 644 | 616 | 583 | 551 | 495 | 456 | 415 | 360 |
| Mean | ... | 665 | 627 | 602 | 563 | 526 | 474 | 436 | 388 |

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TABLE V. *Mean monthly values of the magnetic declination at Orcadas, February, 1905, to December, 1912.*

*Latitude:* 60° 45′ S.; *longitude:* 45° 01′ W.

[*D* = East 4°+]

| Month | 1905 | 1906 | 1907 | 1908 | 1909 | 1910 | 1911 | 1912 |
|---|---|---|---|---|---|---|---|---|
| | ′ | ′ | ′ | ′ | ′ | ′ | ′ | ′ |
| January | .... | 74.0 | .... | .... | .... | 54.6 | .... | 47.9 |
| February | 80.3 | .... | .... | .... | .... | .... | .... | 47.4 |
| March | 80.2 | .... | .... | .... | 58.6 | .... | 50.6 | 47.5 |
| April | 78.1 | .... | .... | 64.4 | 57.3 | .... | 50.8 | 47.3 |
| May | 76.8 | 72.6 | .... | 63.5 | 57.0 | .... | 50.6 | 47.7 |
| June | 76.2 | 71.3 | .... | 62.8 | 56.4 | .... | 50.0 | 46.3 |
| July | 76.1 | .... | .... | 61.3 | 56.3 | .... | 48.1 | 45.9 |
| August | 75.7 | 71.0 | .... | 60.9 | 56.3 | .... | 48.0 | 45.5 |
| September | 75.2 | 70.3 | .... | 60.5 | 55.9 | .... | 48.2 | 46.0 |
| October | 74.8 | .... | .... | .... | 55.8 | .... | 48.0 | 45.6 |
| November | 75.1 | .... | .... | 59.5 | 55.2 | .... | 47.6 | 45.3 |
| December | 74.2 | .... | .... | 59.1 | 55.2 | .... | 48.2 | 45.1 |
| Mean | .... | .... | .... | .... | .... | .... | .... | 46.4 |

TABLE VI. *Mean monthly values of the horizontal intensity at Orcadas, March, 1905, to December, 1912.*

[H = 25000 γ +]

| Month | 1905 | 1906 | 1907 | 1908 | 1909 | 1910 | 1911 | 1912 |
|---|---|---|---|---|---|---|---|---|
| | γ | γ | γ | γ | γ | γ | γ | γ |
| January | ... | 655 | ... | ... | ... | 431 | ... | 363 |
| February | ... | ... | ... | ... | 438 | ... | ... | 362 |
| March | 688 | ... | ... | ... | 434 | ... | ... | 363 |
| April | 724 | ... | ... | 403 | 443 | ... | ... | 357 |
| May | 733 | ... | ... | 418 | 432 | ... | ... | 356 |
| June | 703 | ... | ... | 431 | 441 | ... | 392 | 346 |
| July | 665 | ... | ... | 440 | 438 | ... | 386 | 345 |
| August | 655 | ... | ... | 432 | 430 | ... | 386 | 336 |
| September | 617 | ... | ... | ... | ... | ... | 388 | 326 |
| October | 623 | ... | ... | ... | 418 | ... | 370 | 322 |
| November | 622 | ... | ... | 445 | 422 | ... | 382 | 317 |
| December | 643 | ... | ... | 483 | 421 | ... | 372 | 328 |
| Mean | ... | ... | ... | ... | ... | ... | ... | 348 |

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TABLE VII. *Values of the inclination at Orcadas, 1905 to 1912.*

| Year | No. of Months | Inclination (South) |
|---|---|---|
| | | ° ′ |
| 1905 | 11 | 54 31.1 |
| 1906 | 8 | 30.6 |
| 1907 | 12 | 24.4 |
| 1908 | .. | .... |
| 1909 | 10 | 26.7 |
| 1910 | .. | .... |
| 1911 | 11 | 26.2 |
| 1912 | 12 | 25.5 |

## ZUR UNTERSUCHUNG DER TAEGLICHEN VARIATION AUF DER GANZEN ERDE.[1]

Die deutliche Veränderlichkeit des täglichen Ganges der magnetischen Elemente von Tag zu Tag macht es nötig, dass bei Untersuchungen, die sich auf die ganze Erde beziehen, nur *streng simultane* Beobachtungen aller Observatorien verwendet werden.

Bei der Benutzung *aller* Tage zur Ableitung der Monatsmittel des Ganges ist diese Bedingung erfüllt, nicht aber bei den vielfach berechneten Mitteln ausgewählter (ruhiger oder normaler) Tage. Gerade diese sind aber von besonderer Bedeutung für verschiedene Aufgaben, vor allem für die Untersuchung der täglichen Variation auf der ganzen Erde und damit für die Weiterbildung der (von A. Schuster begründeten) Theorie der täglichen Variation. Um diese Theorie möglichst exakt durchzuführen und an der Erfahrung zu prüfen, ist es erwünscht, dass Beobachtungen von möglichst *allen* Observatorien benutzt werden. Es gibt aber eine nicht kleine Zahl von Observatorien, die zwar fortlaufende Registrierungen ausführen, denen aber die Mittel fehlen, diese Tag für Tag auszuwerten und zu berechnen, sowie zu publizieren. Manche dieser Observatorien, wenn nicht alle, würden aber gewiss imstande sein, diese Arbeit für eine kleine Zahl von Tagen (etwa für 5 Tage jedes Monats) zu leisten. Wenn man sich also dahin einigte, überall für dieselben 5 Tage jedes Monats den täglichen Gang zu berechnen und zu veröffentlichen, so würden wir hoffen dürfen, in einigen Jahren ein viel reicheres Material zur Untersuchung der täglichen Variation auf der ganzen Erde zusammenzubringen, als dies bisher möglich gewesen ist. Es kommt hinzu, dass es an sich von

[1] Internationale Erdmagnetische Kommission. Rundschreiben des Bureau exécutif an sämtliche erdmagnetische Observatorien.

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Interesse ist, das Phänomen der Variation gerade an ruhigen Tagen, die die einfachsten Verhältnisse darbieten, zu studieren.

Veranlasst durch diese Erwägungen, hat das Bureau exécutif zunächst eine Anzahl von Hauptobservatorien ersucht, in ihren Publikationen ausser den bisherigen Angaben auch noch *den mittleren täglichen Gang für die 5 ruhigen Tage, die von dem Kgl. Niederländischen Meteorologischen Institut auf Grund der internationalen Charakterzahlen ausgewählt werden,* zu berechnen und zu publizieren.

Diesem Ersuchen ist überall entsprochen worden, und nach den bis jetzt vorliegenden Erklärungen werden die folgenden Observatorien künftig den täglichen Gang im Mittel der 5 internationalen ruhigen Tage jedes Monats in ihren Publikationen mitteilen: *Apia, Batavia, Cheltenham, De Bilt, Eskdalemuir, Honolulu, Pawlowsk, Potsdam, Sitka, Vieques, Tucson.*

Nachdem somit bereits unter einer nennenswerten Anzahl von Observatorien eine Vereinbarung erzielt worden ist, wendet sich das Bureau exécutif an die Direktionen der übrigen Anstalten mit dem Ersuchen, möglichst bald dieser Vereinbarung beitreten zu wollen.

Indem die Unterzeichneten dieses Ersuchen hiermit übermitteln, fügen sie zur Verhütung etwaiger Zweifel oder Unklarheiten noch die folgenden näheren Angaben hinzu:

(1.) Die Daten der ruhigen Tage finden sich in der jährlichen Publikation: Caractère magnétique de l'année . . . , die allen Observatorien zugesandt wird. Auf Wunsch sendet das Meteorologische Institut in De Bilt weitere Abdrücke.

(2.) Die Tage sind nach bürgerlicher Greenwicher Zeit—von Greenwicher Mitternacht bis Mitternacht—zu nehmen.

(3.) Es ist erwünscht, dass die mitgeteilten Stundenwerte von dem non-cyclic effect befreit sind. Wenn dies nicht der Fall ist, so sind *25* Stundenwerte (für $0^h$ $1^h$ . . . $24^h$) mitzuteilen, damit die Korrektion nachträglich angebracht werden kann.

(4.) Es ist erwünscht, dass die Abweichungen der Stundenwerte vom Tagesmittel berechnet und veröffentlicht werden. Wenn ausserdem die absoluten Werte angegeben werden, so ist zu wünchen, dass dies auch für die *einzelnen* Tage und nicht nur für das Mittel der 5 Tage jedes Monats geschieht.

(5.) Es ist erwünscht, dass der Gang nicht nur für die direkt beobachteten Elemente *D, H, Z* (nach der internationalen Schreibweise oder *D, H, V* nach der besonders an englischen Observatorien vielfach üblichen Bezeichnung), sondern auch für die Komponenten *X, Y* (oder *N, W*) veröffentlicht wird.

*Der Vorsitzende:*
M. RYKATCHEW.

*Der Schriftführer:*
DR. AD. SCHMIDT,

*Posdam, den 1. Nov. 1913.*

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## THE FIRST MAGNETIC OBSERVATORY IN POLAND.

I am very happy to be able to inform the readers of the Journal that a new magnetic observatory is to be erected this year in Swider, near Warsaw. The erection of this observatory is connected with the magnetic researches, which are now being carried on by me in Poland. For reduction of these observations to a certain epoch the Potsdam magnetograms will not suffice, as this observatory, though the nearest one, is still too far from the region of our survey. At all events the newly erected observatory will be of a permanent character.

The Observatory will be provided with registering instruments (Adolf Schmidt's system) made by the firm of O. Toepfer at Potsdam. For the absolute determinations, there will be used a large Sartorius magnetic theodolite (like the one used in the Tsingtau Observatory), and an earth inductor made by G. Schulze, of Potsdam. All of the instruments, besides the magnetometer, are nearly ready. The magnetometer will be completed in the winter. Thanks to the director of the Prussian Meteorological Institute, G. Hellmann, and to the director of the Potsdam Magnetic Observatory, Adolf Schmidt, all the instruments will be tested at Potsdam. Everything in my power will be done to ensure that the new observatory will be in active operation in 1914. Further details will be supplied later. ST. KALINOWSKI.

*Physical Laboratory,*
*Museum of Industry and Agriculture,*
*Warsaw, Sept. 9, 1913.*

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## REGARDING MAGNETIC OBSERVATIONS, APRIL 17, 1912.

I am much obliged to Mr. de Moidrey for his kindness in publishing the magnetic curves obtained during the eclipse of the Sun on April 17, 1912, at Lu-kia-pang.[1] When I stated in my note[2] that it would be very desirable to have some data from stations situated to the east of Warsaw, I had in mind some point much nearer than Lu-kia-pang, for example at a distance about equal to that between Beuthen and Potsdam from Warsaw. It is only in such a case that one could account for the difference between the data of Warsaw, Beuthen and Potsdam. The curves of De Bilt published by Mr. G. van Dijk[3] seem to confirm my supposition. In the curve of declination, given by Mr. de Moidrey, one can find some resemblance to the curves of the European observatories; the variations of the declination are smaller than they usually are at that time. ST. KALINOWSKI.

*Physical Laboratory,*
*Museum of Industry and Agriculture,*
*Warsaw, Sept. 9, 1913.*

[1] *Terr. Mag.*, v. XVIII, p. 53. [2] *Terr. Mag.*, v. XVII, p. 154. [3] *Terr. Mag.*, v. XVIII, p. 51.

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# NOTES

*10. Professor L. Palazzo,* pursuant to instructions from the Italian Minister of Colonial Affairs, investigated during the spring and summer of this year, the seismic conditions in the African colony of Italy, Eritrea, on the Red Sea, and arranged for the erection of a seismological station in the chief town, Asmara, where he installed a seismograph. Besides gathering valuable material for seismological studies, he also determined the magnetic elements at 16 stations in Eritrea and along the Red Sea, among which was Massaua, this being a reoccupation of a former station and thus yielding secular variation data.

*11. Personalia. Walter Brückmann* was promoted to the position of "Observator" in the Berlin Meteorologisches Institut. *S. Chapman,* Chief Assistant at the Royal Observatory, Greenwich, has been elected Fellow of Trinity College, Cambridge. *Prince Galitzin* has succeeded *General M. Rykatchew* as director of the Observatoire Physique Central Nicolas at St. Petersburg. The eminent seismologist, *John Milne,* died at his home on the Isle of Wight, July 31, aged 63 years. *H. Mohn* has retired from his professorship at the University of Christiania, as also from the directorship of the Norwegian Meteorological Institute, and is succeeded by *Aksel S. Steen. H. Knox Shaw* has been appointed Superintendent of the Helwân Observatory, Egypt. *Arthur Schuster's* new address is: Yeldall, Twyford, Berks, England. *O. Venske* has been appointed permanent observer at the Potsdam Magnetic Observatory. The following new appointments have been made during 1913 in the Department of Terrestrial Magnetism of the Carnegie Institution of Washington: *W. F. G. Swann,* formerly assistant lecturer and demonstrator in Physics in the University of Sheffield, chief physicist; *C. R. Duvall,* formerly computer in the Office of the Coast and Geodetic Survey at Washington, expert computer; *W. F. Wallis,* for many years magnetic observer in the Coast and Geodetic Survey, magnetician; *W. C. Parkinson,* formerly at Eskdalemuir Observatory, and *D. M. Wise,* of Bucknell University at Lewisburg, Pennsylvania, magnetic observers; *F. Brown,* formerly at the Greenwich Observatory, assistant observer to *E. Kidson,* in charge of magnetic survey of Australasia.

*12.* The *Carnegie* arrived at Brooklyn, New York, on December 19, 1913. There has thus been successfully concluded, under the command of *W. J. Peters,* the circumnavigation cruise of nearly 70,000 miles, begun in June, 1910.



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# *ABSTRACT.*

## MAGNETIC OBSERVATIONS AT THE TUCSON MAGNETIC OBSERVATORY FOR 1909 AND 1910.[1]

The buildings for this observatory were completed in October, 1909. The magnetographs previously in operation at Baldwin, Kansas, were removed to Tucson and installed at the new observatory.

The variation building is a wooden structure, entirely above ground. Temperature insulation is secured by means of air spaces and sawdust packing. Immediately surrounding the instrument room is a 15-inch space filled with sawdust; then a 26-inch air space (corridor); next a 6-inch dead-air space; then a 40-inch space filled with sawdust; and finally a 6-inch free-air space between the studding. Within the instrument room the daily range of temperature is about 0.°1 C., and the annual range about 15°. The instruments are *D*, *H* and *Z* variometers of the Eschenhagen pattern.

The absolute building is also of wood, and is double-walled, with a 24-inch air space between.

A seismograph building was constructed in the summer of 1910. This is a monolithic concrete structure, partly underground. It is equipped with a Bosch-Omori seismograph having N-S and E-W pendulums.

Daily meteorological observations were made with a set of instruments furnished by the U. S. Weather Bureau.

The magnetograph record began in November, 1909, and the seismograph record in September, 1910.

The present report gives in tabular form the following data: (a) Results of scale value and base-line determinations; (b) diurnal variations of *D*, *H*, *I*, *X*, *Y*, *Z* and *F*; (c) monthly means of *D*, *H*, *I*, *X*, *Y*, *Z* and *F*; (d) hourly values of *D*, *H* and *Z*; (e) earthquakes; and (f) principal magnetic disturbances.

There are also reproductions of the magnetograms showing some of the principal magnetic disturbances occurring during the year 1910.

W. F. WALLIS.

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(Including Atmospheric Electricity, Earth Currents, Polar Lights, and General Radioactive Phenomena.)

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